OKANOGAN COUNTY

INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN

Prepared by OCNWCB

Contributions by:
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Bureau of Reclamation
USFS
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EXECUTIVE SUMMARY

Aquatic noxious weeds are a detriment to the health and water quality of the lakes and rivers in Okanogan County. This plan addresses these known infestations of aquatic noxious weeds and outlines control options for noted species. It will also lay a foundation to control as yet unknown infestations of new aquatic noxious weeds. Control options will vary by waterbody, local needs, and funding.

A 2014 comprehensive survey of the Okanogan, Similkameen, Methow and Columbia Rivers as well as several priority lakes with high levels of public access will serve as baseline data for monitoring and control activities as needed, or desired, to mitigate the impact of invasive vegetation in or adjacent to our waters. Lakes included in the survey are Alta, Chopaka, Conconully Reservoir, Leader, Omak, Palmer, Patterson, Pearrygin, Salmon, Sidley and Whitestone. DNR (Dept. of Natural Resources), Okanogan Conservation District, OCNWCB and DOE (Dept. of Ecology) provided funding for these surveys. Both Spectacle and Osoyoos have been surveyed (2010 – 2013) recently and treatments have begun.

Further surveys must take place for secondary lakes, those with less public access or waters unsuitable for vegetative growth excepting the riparian zone surrounding the lake. Funding will continue to be sought for these additional surveys. Partners in the Okanogan County Coordinated Weed Management area will continue to seek funding to survey waters within their individual jurisdictions. These surveys, and the data collected will be incorporated into this document.

Eurasian watermilfoil (Myriophyllum spicatum or E. milfoil) is a commonly found, submersed aquatic noxious weed that proliferates to form dense mats of vegetation in the littoral zone of lakes and reservoirs. It reproduces naturally by seed and fragmentation, with primary reproduction from fragments that “hitch-hike” on boat trailers from one lake to another. E. milfoil is present in many of the lakes and rivers of Okanogan County.

E. Milfoil can degrade the ecological integrity of a water body in just a few growing seasons. Dense stands of milfoil crowd out native aquatic vegetation, which in turn alters predator-prey relationships among fish and other aquatic animals. E. Milfoil can also reduce dissolved oxygen – first by inhibiting water mixing in areas where it grows, and then as oxygen is consumed by bacteria during decomposition of dead plant material. Decomposition of M. spicatum also increases existing nutrient levels which can contribute to increased algal growth and related water quality problems. Further, dense mats of M. spicatum can increase the water temperature by absorbing sunlight, create mosquito breeding areas, and negatively affect recreational activities such as swimming, fishing, and boating.

Other submersed and emergent aquatic plant species can be equally detrimental to our waters, and many are state listed noxious weeds. Increasing awareness of the importance of water quality and the negative impacts that noxious weeds can have to those resources has necessitated that Okanogan County devise an Integrated Aquatic Vegetation Management Plan (IAVMP). Because of the complexity of this document and that it is intended to provide information and options for many individual waters, all the waters covered under the initial survey are listed separately along with pertinent information. Additional waters will be added as supplemental data as surveys are completed. All information obtained for this plan will be housed at the OCNWCB office, currently at RM 102 of the County Courthouse.

This Integrated Aquatic Vegetation Management Plan (IAVMP) is a planning document developed to ensure that the best available information about the waterbodies and the watershed are utilized prior to initiating control efforts. Members of the county and various State and Federal agencies have worked together to develop this IAVMP and ensure a comprehensive approach. To tackle the difficult task of generating community concern and educate regarding appropriate action for an environmental issue, a core group of partners – all collaborators with the Okanogan County Coordinated Weed Management Area have formed a Steering Committee.

Through their work, the Steering Committee will educate the wider community about the problem, and inspire them to contribute feedback about potential treatment options. The Steering Committee ultimately agreed upon an integrated treatment strategy, which includes a combination of chemical, bio control, and manual, mechanical, and cultural control methods as appropriate for individual waterbodies within Okanogan County and under various jurisdictions. While there is concern over mechanical methods such as harvesting or rototilling, they are not a first option of control and other methods will have preference.

This plan presents lake and watershed characteristics, details of the aquatic weed problems at individual waterbodies, the process for gaining community involvement, discussion of control alternatives, and recommendations for initial and ongoing control of noxious aquatic weeds threatening those waterbodies.

PROBLEM STATEMENT

Okanogan County has a plethora of lakes and rivers, which are home to native plant and animal species. With the exception of Osoyoos and Spectacle lakes, there has not been a consistent comprehensive survey of our waterbodies in recent history. The Dept. of Ecology maintains an amount of data pertaining to many of our lakes, but inconsistent survey schedule and lack of historical GPS/GIS data does not allow for needed monitoring or control of these sites with invasive vegetation. While many of these waters are considered waters of the state, Washington State does not have the resources necessary to consistently survey, monitor nor control invasive noxious weeds within these waters and the onus of that effort falls to local landowners. DOE does partner in these efforts through Planning and Implementation grants, available as funding allows.

At this time, there is no readily accessible resource in Okanogan County for these landowners to go to as they seek answers regarding aquatic noxious weed identification and biology, viable control options, or permitting processes needed for control efforts in aquatic situations. This document is meant to remedy the situation and will be available through DOE, our CWMA partners, OCNWCB website (www.okanogancounty.org/nw), or at the Noxious Weed Office.

Okanogan County relies heavily on agriculture and tourism as economic drivers. Lakes and rivers infested with noxious weeds are not conducive to optimal recreational uses and can be considered a safety hazard. In addition, these infested waters reduce agricultural irrigation practices, further reducing our economic viability.

Due to prolific growth of several species of dense, invasive aquatic noxious weeds, our waterbodies are in danger of losing their aesthetic beauty, wildlife habitat, and recreational attributes as well as potentially decreasing the profitability of agricultural production. If left untreated, the most common of these noxious weeds, Eurasian water milfoil (Myriophyllum spicatum), will further displace native aquatic vegetation, preventing most recreational uses and eliminating badly needed wildlife habitat. As Engle (Engle 1987) and Newroth (Newroth 1985) point out, there are negative effects for sport fish species such as Large Mouth Bass and Salmonids via reduced spawning success. More specifically, Milfoil can reduce water quality via a number of mechanisms, including increased nutrient loadings; reduce dissolved oxygen and changes in water temperature (Bates et al. 1985; Madsen 1997). Increasing development in the county is likely to increase the number of people using our lakes and rivers in coming years, which accelerates the magnitude of the loss of beneficial uses to the community.

The shallow shoreline areas of our waterbodies provide an excellent habitat for aquatic plants and wildlife. Aggressive, non-native species such as Purple loosestrife and Yellow flag iris have invaded several waterbodies and are colonizing much of the near-shore aquatic habitat.

Milfoil is the most significant submersed invasive threat at this time, but other noxious weeds have also invaded our waters. These include Fragrant water lily (Nymphaea odorata), Purple loosestrife (Lythrum salicaria), Curlyleaf pondweed (Potamogeton crispus) and Yellow flag iris (Iris pseudacorus). All of these species are considered noxious weeds as listed in WAC 16-750. None of the native aquatic plants in the system are a management issue at this time. The native plants provide important benefits to the aquatic system and are not impeding any of the recreational uses of the lake. Removing the noxious invaders will reduce the degradation of the system and allow the dynamic natural equilibrium to be re-established.

Unfortunately, these invasive plants concentrate in the near shore zone, which is also that portion of the lake that is valued and utilized most by lake residents, visitors and our agricultural communities. Dense weed growth poses a threat to swimmers, and the portions of the waters where people can fish are shrinking. E. Milfoil, Curly leaf pondweed and Fragrant water lilies foul fishing gear, motors, and oars. It is no longer possible to troll through large portions of area lakes. Irrigation from these waters becomes unpredictable and potentially hazardous when removing aquatic vegetation from intake valves.

As a group these invasive plants:

- Pose a safety hazard to swimmers and boaters by entanglement
- Snag fishing lines and hooks, eventually preventing shoreline fishing
- Crowd out native plants, creating monocultures lacking in biodiversity
- Significantly reduce fish and wildlife habitat, thereby weakening the local ecosystem as well as degrading wildlife and wildlife viewing opportunities
- Pose a threat to adjoining ecosystems
- Impact oxygen levels
- Threaten a re-emerging Sockeye salmon run
- Pose a threat to the profitability of agriculture

Immediate action is necessary to control Eurasian water milfoil and other invasive aquatic weeds. If left unchecked, our waters will soon become heavily infested, severely degrading our waters ecosystems and making the non-native vegetation even harder to eradicate and causing significant impact downstream.

COMMUNITY INVOLVEMENT

History

Okanogan County residents have typically performed their own weed control by hand pulling, chemical applications, plastic barriers or bio-control. When it came to aquatic or shoreline weeds, these control actions have been individually performed, often without training, aquatic labeled herbicides, or necessary permits. If aquatic herbicides were used, they were purchased from internet distributors and applied in the dark of night. However, things change and in this case, county residents drove the change.

Since 2006, residents and recreationists have expressed concern regarding the increasing infestations of aquatic weeds in our water bodies and the limited opportunities for safe recreation. This concern prompted OCNWCB to actively engage in aquatic noxious weed education and control.

In 2008, after repeated appeals from Palmer Lake Area Residents Association (PLARA) for assistance in controlling milfoil infestations, OCNWCB applied for and received coverage under the NPDES Permit (National Pollutant Discharge Elimination System and State Water Discharge General Permit # WAG993000) held by Washington Dept. of Ecology (DOE). PLARA members were actively involved and paid for control costs with assistance from Bureau of Land Management, which owns the boat launch and water access site at the south end of the lake. Several meetings were held with landowners around the lake and an education process began for both PLARA and OCNWCB.

At this time, we investigated several control options for invasive aquatic vegetation, including bio controls and benthic barriers. We began to provide information about milfoil on our Weekly Radio Report and encouraging water users to take extra caution when entering lakes infested with Eurasian watermilfoil.

Lake Osoyoos residents also began to notice an increase in milfoil and approached OCNWCB for assistance and education. In 2010, OCNWCB added Lake Osoyoos to the DOE Permit. Because of the joint border with Canada running through the lake, and concerns from Canada regarding the use of herbicides and potential drift, a voluntary buffer was established at 1300' south of the border. It was agreed that there would be no herbicide use within the buffer and the Lake Osoyoos Association (LOA) would work with the Okanagan Basin Water Board (OBWB) to potentially allow for use of their harvester within the buffer area. LOA and OCNWCB applied for and received a Planning grant from DOE and began an educational campaign that led to further milfoil related radio reports as well as a brochure and handout regarding identification and detailing "Clean, Drain, Dry" principles. LOA has had an aggressive education campaign at local boat launches and has spent at least one day every weekend during boat season distributing handouts and talking to members and visitors about milfoil control, invasive species, and "Clean, Drain, Dry".

In 2011, OCNWCB worked with other Weed Boards and State and Federal agencies to create the International Control of Invasive Aquatic Vegetation for the Upper Columbia River System Cooperative Weed Management Area (CWMA). This CWMA was established as a means of communication between the cooperators. An annual meeting occurs to discuss issues and provide support in education and control efforts. Individual agencies have been working independently and often repeating common mistakes or "re-inventing" control plans and methods. By communicating and working together, we can increase the effectiveness of both our education and our control efforts.

In 2013, Spectacle Lake was added to the Permit, with the first aquatic treatment occurring in 2014. Spectacle Lake is managed by Whitestone Irrigation District and is subject to water drawdowns to provide irrigation water to surrounding orchards under Global Gap standards. With three resorts and several private landowners sharing the shoreline, public pressure is high to restore water quality and recreation. While originally there was not a formal organization to drive control efforts on the lake, the Spectacle Lake Association was formed and formalized through Washington State.

At this time, Salmon Lake (Upper Conconully) is also seeking milfoil control. This Lake is under Bureau of Reclamation jurisdiction. Conconully Lake is also expressing interest in implementing control measures. A survey has been completed of the lower Okanogan and the Columbia River from the Canadian Border to Rock Island Dam. The survey, funded by CWMA partner DNR, crossed many jurisdictions, involved multiple partners and required high levels of cooperation. An additional survey, performed by Okanogan Conservation District and funded by DOE, covered the upper Okanogan, Methow, and Similkameen rivers as well as the lakes originally covered in this document. We expect further lakes to express interest in controlling aquatic weeds as awareness continues to increase and additional lakes are surveyed.

Community commitment
OCNWCB has maintained an aggressive terrestrial noxious weed program for many years and the landowners and managers within the county have shown their dedication to weed control efforts. In many cases they have gone beyond the requirements of RCW 17.10 and instigated control efforts on non-mandatory control species and worked across property boundaries and jurisdictions to educate and assist others in developing and implementing a control plan. We have found this same dedication when dealing with the lakes currently covered by the permit and expect it to be consistent throughout the county.

OCNWCB currently holds the permit, through DOE, for Palmer, Osoyoos and Spectacle Lakes. We are committed to assisting in integrated control efforts by maintaining the permit for these lakes. The communities surrounding these lakes have demonstrated their concern regarding the increasing infestations of Eurasian watermilfoil and other non-native weeds. They have committed time and resources to performing survey, control and monitoring efforts as well as educating neighbors and visitors about the negative impact of aquatic noxious weeds.

The option to add additional lakes or waterways for invasive aquatic vegetation will be available upon request by shore owners, lake associations, or control requirements mandated by the Washington State Noxious Weed Law, RCW 17.10.

Public Consensus
The growing amount of Eurasian watermilfoil and other aquatic noxious or nuisance weeds has caused an increase of public awareness that control efforts must occur to ensure recreational safety, continued agricultural usage, habitat for native species, and water quality. We expect that control efforts will occur and shoreline owners and adjacent communities will work together to mitigate the impacts of noxious weeds in their waters.

However, with the variety of lakes and waterbodies involved in this plan, we do not expect complete agreement for any preferred control option and will work to incorporate a specific plan that fits the needs of individual waterbodies.

Continuing Community Education
OCNWCB will offer the means by which the community will receive ongoing education. To ensure that community education is consistent with best available science and water quality standards, OCNWCB will continually educate themselves regarding aquatic weed issues by maintaining contact with aquatic commercial applicators, Dept. of Ecology, Washington State Noxious Weed Control Board and others as circumstances dictate.

Pertinent information will be distributed through community meetings. Individual waterbodies will be surveyed and baseline data acquired regarding the noxious weeds present, then we can focus education efforts to address the issues. Each lake will receive information regarding IPM options and control methods. Discussions will establish which preferred method would be more effective in their individual lake.

Watershed mailings will occur when distribution of a species is widespread, such as E. milfoil. OCNWCB has been very successful in distributing educational handouts through USPS Every Door Direct Mailings. Utilizing such a method will enable us to reach more people possibly affected by water quality issues than just those along the shoreline. Previous distributions have been kept and displayed by residents throughout the growing season.

KOMW is a local radio station that works with OCNWCB to air a weekly educational segment regarding noxious weed issues. This enables the Weed Office to reach 13,000 listeners each week. E. Milfoil segments have aired repeatedly, already increasing awareness and propensity to action.

Aquatic noxious weed brochures and identification cards will be available and widely distributed to raise awareness among individual landowners of potential non-native invasive plants. A better-educated community of residents and lake-users will be more likely to identify and report noxious aquatic weeds and other potential problems. These educational materials will also be available through area businesses that support recreational opportunities on the water. DOE and LOA have established “Clean, Drain, Dry” handouts which gives users direction and establishes the need to protect our waters. OCNWCB has created an E. Milfoil brochure which assists with identification and promotes “Clean, Drain, Dry” principles. Additional handouts will be created detailing species that we know to be present in the county and those known to be near and highly aggressive. Educating community members and other water users will illuminate the relationship between human behaviors and water quality. Each lake resident will be provided information on how to reduce the amount of pollutants entering the lake from their property. Property owners with lakeside lots will receive information on lake-friendly landscaping, subsequently ensuring a healthier lake environment.

Establishment of signs depicting aquatic invasive species will inform lake-users of the presence/absence of noxious aquatic weeds, how to prevent their spreading them from lake to lake, and promote “Clean, Drain, Dry” protocols. Many public launches currently have signage, but often they are dated and do not engage a person to take action regarding noxious weeds or other invasive species. These signs need to be updated and signs must be posted at all public launches to increase awareness and have a consistent message.

Volunteers (community members on individual waterbodies) will undergo identification training of aquatic noxious weeds, enabling them to provide support to continuing control efforts through surveying and monitoring activities. These volunteers are established on Osoyoos and Spectacle and are providing valuable information on weed densities, locations, and water quality.

OCNWCB continues to provide education regarding aquatic noxious weeds and with the increased aquatic education and resulting public awareness of aquatic weeds and associated issues, we expect further lakes to come forward and discuss their particular aquatic noxious weed issues.

WATERSHED AND WATERBODY CHARACTERISTICS

Watershed Characteristics

The Okanogan River Watershed encompasses about 2,100 square miles in Washington State. This watershed extends north and south from the Canadian border to the Columbia River. The physical northern boundary of the watershed is actually in the Canadian province of British Columbia where another approximately 6,000 square miles is located. Mean precipitation over the Okanogan River Watershed is 15 inches.

The Okanogan River flows through Osoyoos Lake, which extends across the international boundary, and continues southward to empty into the Columbia River near Brewster. However, an even greater inflow from Canada is from the Okanogan's major tributary, the Similkameen River. The Similkameen crosses the border west of the Okanogan and enters the Okanogan River near the south end of Osoyoos Lake. About 2.1 million acre-feet of water enters the watershed from Canada as streamflow; about 75 percent of this amount is from the Similkameen River. The outflow from the watershed at Brewster is estimated to be 2.2 million acre-feet.

This watershed is within the Columbia Basin, Cascades, and Northern Rockies ecoregions. The eastern and western boundaries of the basin are steep, jagged ridgelines at elevations ranging from 1,500 feet to more than 5,000 feet above the basin floor. The floodplain of the Okanogan River valley averages about a mile in width, and descends from an elevation of about 920 feet at the international boundary to about 780 feet at the river's confluence with the Columbia River. Osoyoos Lake occupies the northern most 4 miles of the valley floor and extends several miles into Canada.

The soils in the watershed include shallow to moderately deep sandy loam and silt loam. These soils are formed from volcanic ash and pumice (ejected from Glacier Peak to the west centuries ago), glacial till and outwash, alluvium, lake sediments, and wind-laid silts.

There are approximately 32,855 people living in the Okanogan Basin. The primary population centers are Omak and Okanogan. The majority of people live in unincorporated areas. The largest land uses in the basin are forested lands (51%) and agricultural lands (39%).
(Okanogan County Planning & Development website)

Waterbody Characteristics

Columbia River comprises some 260,000 square miles, from its headwaters in British Columbia, Canada, to its mouth at Astoria, Ore., bordering Washington and Oregon. It includes parts of seven states, 13 federally recognized Indian reservations, and one Canadian province. Nineteen percent of the watershed is in Washington.

The average annual flow for the Columbia River at The Dalles, Oregon is approximately 190,000 cubic feet per second (cfs) (1 cfs = 448.8 gallons per minute). The river's annual discharge rate fluctuates with precipitation and ranges from 120,000 cfs in a low water year to 260,000 cfs in a high water year.

After dams were constructed along the river for flood control and power production, the flow regime of the river changed. Records kept since 1878 show that flows were much higher in the spring and lower in winter before dam construction. In addition, the velocity of the water moving down the river was significantly greater before dam construction began in the 1930's. In 1917, Washington adopted a water code to help manage water allocations from surface water bodies in the state, including the Columbia River.

Since the water code was adopted, the state has allocated 768 surface water and 1,379 groundwater rights on the mainstem Columbia River.

Okanogan River originates in the Cascade Mountains north of the international border between British Columbia (BC) and Washington State. On the BC side the Okanogan River is made up of a series of lakes and a free-flowing river coming from Lake Osoyoos, which straddles the boundary. Once it crosses the border into Washington, it flows 78 miles to its confluence with the Columbia River.

The Okanogan River's primary tributary is the Similkameen River, which enters the Okanogan River just downstream of Oroville, Washington. The Similkameen River normally contributes three-quarters of the combined flow in the Okanogan River. About 20 small tributary streams also drain the 2,600 square miles of the Washington portion of the basin. The basin is lightly populated. Agriculture, forestry, mining, and recreation are the major land-use activities in the Okanogan watershed.

The Okanogan River and several tributaries are listed on Washington State's 303(d) list of impaired waters because they do not meet the EPA human health criteria for DDT and PCBs in edible fish tissue, as well as for non-attainment of Washington's chronic criteria for DDT in water. When water bodies are placed on the 303(d) list, the Clean Water Act requires that the state develop a Total Maximum Daily Load (TMDL) for that waterbody. The TMDL determines the extent of the pollutant problem in the water, and establishes the maximum load of that pollutant that the water body can accept without violating the state's surface water quality standards. The TMDL is accompanied by an implementation strategy or plan, worked out between the state and local citizens, governments, and special interest groups, to help move the water body to clean water.

Similkameen River becomes a tributary of the Okanogan River at Oroville, Washington. Mining, forestry, agriculture, and recreation are the major land-use activities in the Similkameen watershed.

The Similkameen River is listed on the Washington State 303(d) list because it does not meet the human health criteria for arsenic. The major source of arsenic appears to be a legacy resulting from historical mining activities, mostly in British Columbia between Hedley and the U.S. border. Washington State sources are Palmer Lake, likely from periodic flooding and sediment deposit by the Similkameen River, possible inputs from Sinlahekin Creek, and re-suspension of contaminated sediments.

Methow

Alta Lake is located at latitude 48.01167 & longitude 119.9386. The lake is about 2 miles long, .5 miles wide and covers 219 acres. It sits at an elevation of 1,170 feet. A State Park is located on the lake and a nearby golf course community provides additional recreation for visitors. Primarily owned by WDFW and USFS, there is a small amount of privately owned ground.

WDFW manages Alta Lake as an opening day, intensive harvest trout fishery through stocking hatchery fish and controlling undesirable fish species with periodic piscicide treatments.

DOE surveys of the lake occurred in 1995 and 2007 and found various native species of aquatic vegetation but no notations were made regarding noxious weeds.

A 2014 survey found a small site of Eurasian watermilfoil, multiple sites of Russian olive, and a site of Phragmites. The Phragmites will be followed up on to ascertain if the species is native or non-native.

Chopaka Lake is located at latitude 48.90361 & longitude 119.6925. It covers 149 acres and sits at an elevation of 2,921 feet. This lake is primarily owned by BLM and DNR, with a small amount of private ownership.

WDFW manages Chopaka Lake as an opening day, quality trout fishery through stocking hatchery fish and controlling undesirable fish species with periodic piscicide treatments.

A DOE survey occurred in 1999 and noted a small infestation of Yellow flag iris. The 2014 survey did not locate a site of Yellow flag iris, but did note two sites of Knotweed.

Blue Lake is located at latitude 48.682923 & longitude - 119.6880407. The lake averages 205.4 acres at an elevation of 1,690 feet. It is completely surrounded by WDFW lands and they manage the camp area and launch.

DOE surveyed the lake in 1999 and again in 2007. Reed canarygrass was the only noxious weed noted. The 2014 survey found a couple sites of E. milfoil and several sites of Russian olive.

Buffalo Lake is located on the Colville Indian Reservation at latitude 48.0625 and longitude 118.8917, covering 542 acres. It sits at an elevation of 2,042 feet with an average depth of 63 feet and a maximum depth of 121 feet.

It is a large, cold water lake located in Okanogan County in Nespelem River drainage within the upper Columbia Sub-basin. Several intermittent inlets and one unnamed inlet are located along this lake's northern and eastern shorelines along with several submerged springs.

The lake sits in an area of ancient basaltic lava flows with rolling hills covered by mostly sage and bunch grasses.

DOE performed surveys on the lake in 1995 and again in 2008. There were no noxious weeds located within the lake bed.

The 2014 survey found a large area infested with Eurasian watermilfoil.

Connors Lake is located at latitude 48.75083 and longitude 119.6583 within the Sinlehekin Wildlife Area. It sits at an elevation of 1504 feet and covers almost 35 acres.

The lake was surveyed in 2007 by DOE and no noxious weeds were found. The survey in 2014 also found no noxious weeds.

Conconully Reservoir is located at latitude 48.53778 & longitude 119.7472 and covers 450 acres and sits at an elevation of 2287. Water level fluctuations influence access. While quite a bit is privately owned, State Parks and Bureau of Reclamation will also be key participants in any control effort.

WDFW manages Conconully Reservoir as an opening day, intensive harvest trout fishery through stocking hatchery fish.

DOE surveyed the reservoir in 1994, 1997, and again in 2012. In 1997, Eurasian watermilfoil was noted as a level 2 distribution value, which means that it was few plants but with a wide patchy distribution. Curlyleaf pondweed was also noted in 2012 and only a few plants were found.

The 2014 survey noted a vast increase in Curlyleaf pondweed. Control efforts may begin on Bureau and Parks lands in 2014 with aquatic applications for Curlyleaf and Milfoil taking place if needed in 2015.

Salmon Lake (Conconully Lake) is located at longitude 48.55806 & longitude 119.7444. It covers 313 surface acres, reaches depths of about 110 feet and lies at an elevation of 2,324 feet. This lake is primarily owned by the Bureau of Reclamation, but does enter USFS lands at the north end.

WDFW manages Conconully Lake as an opening day, intensive harvest trout fishery through stocking hatchery fish.

Surveys performed by DOE occurred in 1994, 1997, and 2003. Eurasian watermilfoil was noted to be present in large monospecific patches. The reservoir has also been noted to have a possible hybrid between the Eurasian and native Northern milfoils. Reed canarygrass was also noted along the shoreline.

The 2014 survey noted Curlyleaf pondweed and Eurasian watermilfoil primarily around the boat docks and shoreline of permitted cabins. Control efforts have begun to decrease the noted noxious weeds during fall drawn down of the lake. Aquatic applications are scheduled to take place in 2015 with the Bureau of Rec taking the lead.

Fish Lake is located at latitude 48.61 and longitude 119.6842, within the Sinlahekin Wildlife Area. It sits at an elevation of 1806 feet with acreage of 101.6.

Two public access areas with boat launches, campground, and toilets are available.

DOE surveyed the lake in 1994, 1999, and again in 2007. No noxious weeds were noted.

The 2014 survey noted several sites of Purple loosestrife and OCNWCB has noted infestations of Puncturevine in the camp and parking areas.

Forde Lake is located at latitude 48.73667 and longitude 119.6683. Lake Acreage: 8.8.
Elevation: 1,568 feet.

DOE surveyed the lake in 2007 and there were no noted noxious weeds. The 2014 survey also found no noxious weeds.

Leader Lake is located at latitude 48.36139 and longitude 119.6958, covers 155 acres and sits at an elevation of 2,258 feet. A portion on the west end of the lake is owned by DNR and a majority of the lake is privately owned.

WDFW manages Leader Lake as an opening day, intensive harvest mixed species fishery through stocking hatchery trout, managing harvest of the spiny ray fish species, and infrequent piscicide treatments.

DOE surveys occurred in 1996 and 2003 and there were no known infestations of aquatic noxious weeds found. Leader is now open year round. There is a DNR campground at both sides of the lake with boat launching facilities.

Leader Lake was included in the 2014 survey and a significant area of Eurasian watermilfoil was noted.

Omak Lake is located at latitude 48.3225 and longitude 119.4289. The lake covers 3,244 acres at an elevation of 950 feet and is fed by three small creeks. With a volume of 705,000 acre feet and depth of 325 feet, Omak is the largest saline lake in Washington.

A DOE survey occurred in 1996 and there were no noxious weeds noted in the survey. However, in 2004 an infestation of non-native Phragmites was found at the west end of the lake and was invading an infestation of Purple loosestrife.

Data found at http://www.wsu.edu/cctfish/omak.html includes nutrient levels, water temperature, and phytoplankton information which is included as Appendix B.

No additional sites of noxious weeds were noted in the 2014 survey.

Osoyoos Lake is located at latitude 48.95 and longitude 119.4283. The lake's average elevation is about 911 ft. The 62-year average discharge into the Okanogan River at Oroville is 683 cu ft/s. The lake is 10 miles long and covers 5,729 acres, 2,036 of which lay in the US.

DOE performed surveys in 1993, 2005, 2009, 2010, 2011, and 2012. Extensive infestations of Eurasian watermilfoil were noted and have been consistently rated as a distribution value of three by DOE, showing large patches co-dominant with other species. Also noted in DOE surveys were Yellow flag iris, Purple loosestrife, Fragrant waterlily, Reed canarygrass and Curly leaf pondweed. Aquatic treatments began in 2012 for E. milfoil and curlyleaf pondweed. Also noted in Lake Osoyoos were several species of native bio control agents that demonstrate some affinity for E. milfoil over the native Northern Milfoil.

A DMP is in place and the Lake Osoyoos Association (LOA) has worked with OCNWCB and DOE to implement control activities for E. milfoil, and an individual IAVMP has been drafted for Lake Osoyoos and is included in this document as Appendix A. LOA has also actively been collecting water quality data for the lake.

USGS has water quality data for Osoyoos Lake available at http://waterdata.usgs.gov/wa/nwis/uv?site_no=12439000, however, the complexity of the site does not easily allow for printing of available information. DOE also has additional information at http://www.ecy.wa.gov/programs/eap/lakes/wq/docs/lkosook1.html, which is included in Appendix C.

Palmer Lake is located at latitude 48.91083 and longitude 119.6453; it covers 2,032.5 acres and sits at an elevation of 1,150. While the Bureau of Reclamation and Washington Dept. of Natural Resources own a small section of shoreline, the majority is privately held.

WDFW manages Palmer Lake as a year around, intensive harvest mixed species fishery through stocking hatchery kokanee and managing harvest of the spiny ray fish species.

DOE performed surveys in 1994, 1995, 1999, 2005, 2007, and 2010. E. Milfoil was found and given a distribution value of five, denoting a monoculture habitat in 2005. Subsequent surveys have rated a 2 distribution value, a few plants with wide patchy distribution. E. milfoil is the only DOE species found listed as noxious.

The 2014 survey noted extensive areas of E. milfoil, but no other noxious weeds were noted.

There is a BLM access site with concrete boat launch, and a DNR site with gravel launch and camping areas as well as a resort and lodge for accommodations.

Patterson Lake is located at latitude 48.46639 and longitude 120.2497. It covers 160 acres and sits at an elevation of 2,391 feet. While a large portion of the lake is privately held, both DNR & WDFW hold lands as well as Bureau of Reclamation having a stake in control efforts.

WDFW manages Patterson Lake as a year around, intensive harvest mixed species fishery through stocking hatchery trout and managing harvest of the spiny ray fish species.

DOE surveys were performed in 1995 and 1999. Curly leaf pondweed was noted in both surveys, but at reduced levels in 1999, earning a distribution value of two.

There is a WDFW access site with gravel boat launch in addition to a private resort with cabins and small boat rentals.

The 2014 survey found several small patches of E. milfoil and a larger infestation of a hybrid.

Pearrygin Lake is located at latitude 48.49222 and longitude 120.1628. It covers 183 acres and sits at an elevation of 1,928 feet.

WDFW manages Pearrygin Lake as an opening day, intensive harvest trout fishery through stocking hatchery fish and controlling undesirable fish species with periodic piscicide treatments.

DOE surveys were performed in 1995, 1999, and 2007. Purple loosestrife, Reed Canarygrass and Western water hemlock were all noted in the surveys. However, none of these species rated above a distribution value of two, a wide and patchy distribution.

In the 2014 survey, a small site of E. milfoil was found.

There is a State Park with camping and boat launch site, as well as a WDFW access site with gravel boat ramp, and a private resort with camping and gravel boat launch.

Sidley Lake is located at latitude 48.98833 and longitude 119.2156. It covers 107 acres and sits at an elevation of 3,683 feet. All surrounding lands are under private ownership.

WDFW manages Sidley Lake as a year around, low-level harvest trout fishery through stocking hatchery fish.

DOE surveys were conducted in 1996 and 2009. The 2009 survey noted Reed canarygrass along the shoreline. OCNWCB terrestrial surveys also noted the presence of Yellow toadflax along the shore.

The 2014 survey found several small sites of Eurasian watermilfoil.

The lake does have WDFW public access but is limited to a gravel boat launch and no facilities.

Spectacle Lake is located at latitude 48.81528 and longitude 119.5222. It covers 313 acres and sits at an elevation of 1,376 feet. DNR and private lands make up most of the ownership base, but the Bureau of Rec. and WDFW also has stakes in this control effort.

DOE surveys were conducted in 1994, 1996, 1997, 1999, 2005, 2009, and 2012. Purple loosestrife, E. milfoil, Reed canarygrass, and Curly leaf pondweed were found at points of the surveys. A hybrid of the E. milfoil was found, confirmed with genetic analysis, in 2012, and given a distribution value of three.

There are three private resorts with boat launching facilities, as well as WDFW access site with boat launch. Dept. of Natural Resources (DNR) owns a large portion of the southern shore and Bureau of Reclamation has land around the lake. The lake was developed by the Bureau to provide irrigation to neighboring croplands.

WDFW has managed Spectacle Lake as an opening day, intensive harvest trout fishery through stocking hatchery fish and controlling undesirable fish species with periodic piscicide treatments. Recent concerns about water quality from nutrient loading of both rotenone treatment and E. milfoil control have postponed the rotenone application to allow for control of dense infestations of E. milfoil.

A Discharge Management Permit is in place and control efforts have begun on this lake for both Milfoil and Curlyleaf pondweed.

Characterization of Noxious Aquatic Plants in Okanogan County

The plant communities in, and around, Okanogan County lakes and rivers represent a diverse set of ecotypes, with hundreds of species occurring in specific habitats represented in the area. Aquatic vegetation communities serve a wide array of functions, such as supporting food chains, providing habitat for a variety of animal species, intercepting sediment and removing toxic compounds from runoff, and providing erosion control/bank stabilization for lakes and streams.

Ten non-native plant species were identified within and around the many lakes and rivers located in Okanogan County, including two emergent types, and two sub-mergent types and six species commonly found in riparian areas. Emergent plants are plants that are rooted in the sediment at the water's edge but have stems and leaves which grow above the water surface. Floating rooted plants are plants that are rooted in the sediment that send leaves to the water's surface. Sub-mergent plants are plants that are either freely floating or are rooted in the lake bottom but grow within the water column.

Many of Okanogan County's lakes and rivers are known to support Eurasian Watermilfoil throughout the littoral zone, including areas of dense concentration. Purple loosestrife (Lythrum salicaria) is scattered on several lakes and along the river courses, including tributaries. Populations and distribution of L. salicaria have been partially contained by repeated releases of biological controls.

Sporadic surveys have been conducted by the Department of Ecology and the corresponding data is present on their website, and that data is included as an addendum to this plan. Native plants include several pondweed species, Cattails, sedges, Coontail and Northern watermilfoil. The Washington Natural Heritage Program (WNHP) has a Natural Heritage Information System database for rare plant species, select rare animal species, and high quality wetland and terrestrial ecosystems, and this database has species in the vicinity of Okanogan County (See Attached).

http://www1.dnr.wa.gov/nhp/refdesk/lists/communitiesxco/okanogan.html

http://www1.dnr.wa.gov/nhp/refdesk/lists/plantsxco/okanogan.html#key

http://www.wdfw.wa.gov/conservation/endangered/All/

Much of the information provided below is taken directly from the Washington State Noxious Weed Control Board website, and the Washington Dept. of Ecology website. Please view these sites for additional information, including individual and effective control methods, on the following species.

http://www.nwcb.wa.gov/default.asp

http://www.ecy.wa.gov/

Noxious Aquatic Weeds in Okanogan County

Non-native aquatic species known to be present in Okanogan County include several Washington State listed noxious weeds, and these species will be the focus of the plant management efforts in our waterbodies. The term "noxious weed" refers to those non-native plants that are legally defined by Washington's Noxious Weed Control Law (RCW 17.10) as highly destructive, competitive, or difficult to control once established. Noxious weeds have usually been introduced accidentally as a contaminant, or as ornamentals. Non-native plants often do not have natural predators (i.e. herbivores, pathogens) or strong competitors to control their numbers as they may have had in their home range.

WAC 16.750 (Appendix D) sets out three classes (A, B, C) of noxious weeds based on their distribution in the state, each class having different control requirements. County Weed Boards are given some discretion as to setting control priorities for Class B and C weeds. All Class A species located in Okanogan County are targeted for eradication (this includes aquatic species). WAC Chapter 16-752 describes the quarantine list maintained by the Washington State Department of Agriculture. Many of the aquatic species listed below can be found on the Quarantine list and/or the State Noxious Weed List, which also describes control requirements. The aquatic weeds listed below are prioritized by their significance on the State Noxious Weed List.

<u>Class A Noxious Weeds – Eradication is required</u>

Common, Dense flowered, Saltmeadow & Smooth cordgrass (Spartina x anglica, densiflora, patens, & alterniflora

According to Wikipedia, Spartina anglica was at first seen as a valuable new species for coastal erosion control, its dense root systems binding coastal mud and the stems increasing silt deposition, thereby assisting in land reclamation from the sea. As a result, it was widely planted at coastal sites throughout the British Isles, and has colonized large areas of tidal mudflats, becoming an invasive species. New colonies may take some time to become established, but once they do, vegetative spread by rhizomes is rapid, smothering natural ecosystems and preventing birds like waders from feeding. In some areas however, a natural dieback of unknown cause has reversed the spread, and artificial control is no longer necessary where this dieback has occurred.

Dense flowered cordgrass, unlike the other cordgrass species spreads only by seed production.

The cordgrass species are not believed to be plants of concern to Okanogan County due to their preference to saltwater marshes. However, should any be located, eradication will be required due to their classification on the State Weed List.

Floating yellow primrose (Ludwigia peploides)

It is native to many parts of the Americas, but it can be found on many continents and spreads easily to become naturalized. It is well known as a troublesome aquatic noxious weed that invades water ecosystems and can clog waterways. This perennial herb grows in moist to wet to flooded areas. The stem can creep over two meters long, sometimes branching. It spreads to form mats on the mud, or floats ascending in the water. The leaves are several centimeters long and are borne in alternately arranged clusters along the stem. The flower has 5 to 6 lance-shaped sepals beneath a corolla of 5 or 6 bright yellow petals up to 2.4 centimeters long.

The Ludwigia species cause dense mats that form a perfect protective habitat for mosquitoes. This may cause higher rates of the West Nile Virus and other diseases that mosquitoes commonly spread. They are also a serious nuisance for human activity. Leisure activities such as hunting, fishing, and boating can be extremely difficult. Flood risk increases due to the decrease in channel carry capacity. The rapid and uncontrolled growth of water primrose dominates native populations and can damage irrigation and drainage networks of water bodies. Fish can have a hard time moving through these dense Ludwigia populations, which then in turn affect the habitat of surface animals such as birds.

Flowering rush (Butomus umbellatus)

Butomus is the sole genus in the monogenetic plant family Butomaceae, containing the single species Butomus umbellatus, also known as Flowering rush or Grass rush. It is native to Eurasia and grows on the margins of still and slowly moving water freshwater habitats down to a depth of about 9 feet. It has pink flowers. Introduced into North America as an ornamental plant, it has now become a serious invasive weed in the Great Lakes area.

Flowering rush is a perennial. This species has the capacity for both sexual reproduction via seeds and clonal reproduction via rhizome shoots and vegetative bulbils borne on both rhizomes and inflorescences. Fertile introduced populations are highly self-compatible (Eckert et al 2000).

Flowering rush reproduces both sexually through seed and clonally through the production of numerous vegetative bulbils on both the rhizomes and inflorescences and by small-scale rhizome fragmentation.

Both native and introduced populations have a wide variation in seed production, depending on whether the plant is diploid or triploid (Krahulcova and Jarolimova 1993; Eckert et al. 2000; K. Lui, F.L. Thompson and C.G. Eckert unpublished data – as referenced in Eckert et al. 2003).

Spread in Washington is extremely limited and the State Noxious Weed Control Board has listed this species as a Class A noxious weed. No sites are known in Okanogan County at this time.

Hydrilla (Hydrilla verticillata)
Hydrilla is a submersed plant. It can grow to the surface and form dense mats. It may be found in all types of water bodies.

Hydrilla stems are slender, branched and up to 25 feet long. Hydrilla's small leaves are strap-like and pointed. They grow in whorls of four to eight around the stem. The leaf margins are distinctly saw-toothed. Hydrilla often has one or more sharp teeth along the length of the leaf mid-rib. Hydrilla produces tiny white flowers on long stalks.

It reproduces mainly by regrowth of stem fragments; also reproduces by growth of axillary buds (turions) and subterranean tubers; tubers can remain viable for more than 4 years (Van & Steward 1990) and a single tuber can grow to produce more than 6,000 new tubers per m2 (Sutton et al. 1992).

When Hydrilla invades, ecologically important native submersed plants such as Pondweeds (Potamogeton spp.); Tapegrass (Vallisneria americana) and Coontail (Ceratophyllum demersum) are shaded out by its thick mats, or are simply outcompeted, and eliminated (van Dijk 1985). Hydrilla verticillata greatly slows water flow and clogs irrigation and flood-control canals; large mats of fragments can collect at culverts and clog essential water control pumping stations. Hydrilla seriously interferes with boating, both recreational and commercial, and prevents swimming and fishing; major infestations limit sportfish weight and size (Colle & Shireman 1980). Dense Hydrilla infestations can alter water chemistry and oxygen levels (Pesacreta 1988).

Ricefield bulrush (Schoenoplectus mucronatus)
Because this species is only known to infest one site in Washington, it was listed as a Class A species and eradication is required. Given the limited distribution, eradication in this State is entirely possible.

It is a problematic weed in 43 countries, especially in rice fields. It has documented resistance to herbicides making it difficult to control.

Ricefield bulrush is a perennial species that reproduces through seed, rhizomes, and stolons. The root produces several stolons that end with round, dark tubers. When constantly submerged, the tubers will sprout new plants; however, during a drawdown or drought, the tubers will become dormant until conditions are more favorable for growth.

<u>Class B Noxious Weeds – Control is required where designated</u>
Brazilian elodea (Egeria densa)
Brazilian elodea has been a popular aquarium plant and can still be found for sale, usually under the name Anacharis; however, the sale of this plant in Washington is illegal. According to Dept. of Ecology, local and state government and lake residents spend thousands of dollars every year to manage Brazilian elodea infestations in Washington State. The cost of the control project in Silver Lake, Cowlitz County is over one million dollars.

Brazilian elodea forms dense monospecific stands that restrict water movement, trap sediment, and cause fluctuations in water quality. Dense beds interfere with recreational uses of a waterbody by interfering with navigation, fishing, swimming, and water skiing.

Brazilian elodea is a submersed, freshwater perennial herb, generally rooted on the bottom in depths of up to 20 feet or drifting. It is found in both still and flowing waters, in lakes, ponds, pools, ditches, and quiet streams. It tends to form dense monospecific stands that can cover hundreds of acres and persist until senescence in the fall. High water temperatures (greater than 30 degrees centigrade) and high light intensities can cause senescence.

The Dept. of Ecology has additional information on this species and is an excellent source for effective management practices.

Common reed (Phragmites australis)
Common reed is a large perennial grass found in wetlands throughout temperate and tropical regions of the world. Horizontal roots spreading up to 16 feet a year and producing their own root system assist its aggressive spread. These roots make establishment easy and can crowd out native species of vegetation and displace indigenous wildlife.

The non-native Phragmites grows far taller than the native species and can reach heights of almost 20 feet. Other contrasts between the native and non-native species include color and ridging on the stem. Positive identification between the native and non-native species can be difficult and should not be attempted by persons unfamiliar with the varieties. Please contact the OCNWCB, WSDA or DOE for positive identification.

Eurasian watermilfoil (Myriophyllum spicatum)
Eurasian watermilfoil is native to Europe, Asia, and North Africa and occurs in Greenland (Washington State Noxious Weed Control Board, 1995). The oldest record of Eurasian watermilfoil in Washington is from a 1965 herbarium specimen collected from Lake Meridian, King County. It was first identified causing problems in the 1970s in Lake Washington and proceeded to move down the I-5 corridor, probably transported to new lakes on boats and trailers. Eurasian watermilfoil is among the worst aquatic pests in North America. M. spicatum is a submersed, perennial aquatic plant with feather-like leaves. It usually has 12 to 16 leaflets (usually more than 14) on each leaf arranged in whorls of four around the stem. Leaves near the surface may be reddish or brown. Sometimes there are emergent flower stalks during the summers that have tiny emergent leaves. This plant forms dense mats of vegetation just below the water's surface. In the late summer and fall, the plants break into fragments with attached roots that float with the currents, infesting new areas. Disturbed plants will also fragment at other times of the year. A new plant can start from a tiny piece of a Milfoil plant. Milfoil starts spring growth earlier than native aquatic plants, and thereby gets a "head start" on other plants. Eurasian watermilfoil can degrade the ecological integrity of a water body in just a few growing seasons.

Dense stands of Milfoil crowd out native aquatic vegetation, which in turn alters predator/prey relationships among fish and other aquatic animals. Eurasian watermilfoil can also reduce dissolved oxygen – first by inhibiting water mixing in areas where it grows, and then as oxygen is consumed by bacteria during decomposition of dead plant material. Decomposition of M. spicatum also releases phosphorus and nitrogen to the water that could increase algal growth. Further, dense mats of Eurasian watermilfoil can increase water temperature by absorbing sunlight, raise the pH, and create stagnant water mosquito breeding areas. Eurasian watermilfoil will negatively affect recreational activities such as swimming, fishing, and boating. The dense beds of vegetation make swimming dangerous, snag fish hooks, and inhibit boating by entangling propellers or paddles and slowing the movement of boats across the water.

It is likely that the non-native milfoil infestations will continue to expand if left untreated, dramatically increasing negative impacts to the beneficial uses of our waters.

Fanwort (Cabomba caroliniana)
Fanwort, AKA: Green Cabomba, Carolina Fanwort, Fish grass, Washington grass is an aquatic perennial herbaceous plant native to Eastern North America according to Wikipedia. Fanwort is a submersed, sometimes floating, but often rooted, freshwater plant with short, fragile rhizomes. The erect shoots are upturned extensions of the horizontal rhizomes. The shoots are grass green to olive green or sometimes reddish brown. The leaves are of two types: submersed and floating. The submersed leaves are finely divided and arranged in pairs on the stem.
The floating leaves, when present, are linear and inconspicuous, with an alternate arrangement. They are less than 1/2 inch (13 mm) long and narrow (less than 1/4 inch or 6 mm). The leaf blade attaches to the center, where there is a slight constriction. The flowers are white and small (less than 1/2 inch (13 mm) in diameter), and are on stalks which arise from the tips of the stems.

DOE indicates on their Technical Information page that once established this plant could clog drainage canals and freshwater streams, interfering with recreational, agricultural, and aesthetic uses.

While there are no known infestations in Okanogan County, there are sites in Grays Harbor County although the extent is unknown. It is currently listed as a Class B noxious weed in Washington and is designated for control with the exception of Grays Harbor and Cowlitz Counties.

Knotweed - Bohemian, Giant, Himalayan, Japanese (Polygonum x bohemicum, schalinense, polystachyum & cuspidatum)
Knotweeds are a very aggressive species that are capable of crowding out all other vegetation. In addition, the plant can create a fire hazard in the dormant season. The Knotweeds are very similar looking in appearance and growth habits.

Japanese knotweed is an escaped ornamental that is becoming increasingly common along stream corridors and rights-of-way in Washington. The species forms dense stands that crowd out all other vegetation, degrading native plant and animal habitat. This perennial plant is difficult to control because it has extremely vigorous rhizomes that form a deep, dense mat. In addition, the plant can resprout from fragments; along streams, plant parts may fall into the water to create new infestations downstream. According to Wikipedia, Japanese knotweed is listed by the World Conservation Union as one of the world's worst invasive species.

Garden loosestrife (Lysimachia vulgaris)
The apparent ability of Garden loosestrife to invade and establish itself in wetlands threatens the native character of this natural resource. The extent and impact of Garden loosestrife on wetlands indicates it can be significantly aggressive and invasive. Observations indicate Garden loosestrife can out compete Purple loosestrife for necessary nutrients.

Presently, this species has a limited distribution in Washington. The extent of Garden loosestrife populations on Lake Sammamish illustrates that this species can be significantly aggressive and invasive. Control of this species will be complicated by two factors: The species is a rhizomatous (stoloniferous) perennial and it inhabits environmentally sensitive wetland sites. Therefore, from an economic and environmental perspective, it is advisable to prevent the expansion of Garden loosestrife in the state.

Lysimachia vulgaris occurs in moist habitats, such as fens, wet woods, lakeshores, and riverbanks. It has also been planted as an ornamental and used for landscaping purposes. It is a perennial plant that appears to remain in the vegetative stage for some time prior to blooming. The presence of a flowering specimen indicates it has been in an area for some years.

Wand loosestrife (Lythrum virgatum)
Very similar to the more commonly known Purple loosestrife, Wand loosestrife is a European wetland plant that has been introduced to North America and widely sold as an ornamental. Plants grow 3-4 feet tall with showy pink to purple flowers on four-angled stems. It can spread through seeds when cross-pollinated with other Lythrum species or through rooting stem fragments.

It is listed on the Washington State Department of Agriculture's prohibited plants list (quarantine list).

Purple loosestrife (Lythrum salicaria)
Purple loosestrife is native to Europe and Asia and was introduced through ship ballast water to the Atlantic Coast in the mid-1800s (Washington State Noxious Weed Control Board, 1997). In Washington, Purple loosestrife was first collected from the Seattle area in 1929 from Lake Washington. Purple loosestrife is a perennial that can reach 9 feet tall with long spikes of magenta flowers. The flowers usually have six petals, and the stems are squared-off.

Vigorous plants can produce over 2 million tiny, lightweight seeds (120,000 per spike) that are easily spread by waterfowl and other animals (Washington State Noxious Weed Control Board, 1997). Although a prolific seeder, Purple loosestrife can also spread through vegetative production by shoots and rhizomes as well as by root fragmentation. It has a woody taproot with a fibrous root system that forms a dense mat, keeping other plants from establishing in a space.

Purple loosestrife disrupts wetland ecosystems by displacing native or beneficial plants and animals. Waterfowl, fur-bearing animals, and birds vacate wetland habitat when native vegetation is displaced by Purple loosestrife. Loss of native vegetation results in decreased sources of food, nesting material, and shelter for indigenous waterfowl and animals. Economic impacts are high in agricultural communities when irrigation systems are clogged or when wet pastures are unavailable for grazing. Purple loosestrife is aggressive and competitive, taking full advantage of disturbance to natural wetland vegetation caused by anthropogenic alterations of the landscape. Seed banks build for years since seeds may remain viable for up to 3 years. Mono-specific stands are long-lived in North America as compared to European stands, illustrating the competitive edge loosestrife has over other plant species. Purple loosestrife will disperse further up into the wetland if not controlled.

Parrotfeather (Myriophyllum aquaticum)
This rhizomenous perennial exhibits an annual pattern of growth. In the spring, shoots begin to grow rapidly from overwintering rhizomes as water temperatures increase. Rhizomes function as a support structure for adventitious roots and provide buoyancy for emergent growth during the summer. Emergent stems and leaves extend from a few inches to over one foot above the water surface. Underwater leaves tend to senesce as the season advances. Plants usually produce inconspicuous flowers in the spring but some plants may also flower in the fall.

Because of its attractiveness and ease of cultivation, Parrotfeather has been introduced worldwide for use in indoor and outdoor aquaria. It is also a popular aquatic garden plant. However, it has escaped cultivation and spread via plant fragments and intentional plantings. While Parrotfeather may provide cover for some aquatic organisms, it can seriously change the physical and chemical characteristics of lakes and streams. Infestations can alter aquatic ecosystems by shading out the algae in the water column that serve as the basis of the aquatic food web. In addition, the plant provides choice habitat for mosquito larvae. In California, the species is becoming an increasing problem in irrigation and drainage canals. A 1985 survey of irrigation, mosquito abatement, flood control, and reclamation agencies in California indicated that Parrotfeather infested nearly 600 miles of waterways and over 500 surface acres. In Washington, the Longview Diking District estimates that it spends $50,000 a year on Parrotfeather control in drainage ditches. Dense infestations in southern Africa have caused flooding and drainage problems in shallow rivers and streams. The plant can also restrict recreational opportunities in infested bodies of water.

Since all the known plants in the United States are female, the only means of reproduction for this plant in the U.S. is by fragmentation. Plant fragments can move downstream with the current, or attach to boats and animals.

Poison hemlock (Conium maculatum)
Poison Hemlock is a biennial herbaceous plant in the carrot family that grows 3-8 ft. tall. Stems are stout, hollow, ridged, and purple-spotted. It has a thick, white taproot that may easily be mistaken for wild parsnips. It grows into a rosette the first year, (a cluster of leaves growing on the ground) and then flowering stems the next year and producing about 1,000 viable seeds.

All plant parts are poisonous; however, the seeds contain the highest concentration of poison.

An aggressive invasive species, Poison hemlock rapidly colonizes streambanks, vacant lots, roadsides, pastures, and meadows, especially where the soil is moist, outcompeting native plants and desirable forage species.

Water primrose (Ludwigia hexapetala)
Water primroses are non-native perennial herbs found creeping along the shoreline, floating on the water surface, or growing upright. They are robust plants with bright yellow, showy flowers that bloom throughout the summer and willow-like leaves. They are non-native species originally from South America that have been introduced into Europe and North America possibly through the ornamental trade. These non-native primrose species grow in dense mats along shorelines and out into the water.

They favor the margins of lakes, ponds, ditches, and streams. This species has the potential to dominate the shoreline vegetation if introduced to lakes, river, ponds, ditches or streams. This species is very difficult to control once established.

Washington Department of Agriculture lists this species on its quarantine list that prohibits sale, trade, or transport in Washington.

Yellow floating heart (Nymphoides peltata)
Yellow floating heart is a perennial, water lily-like plant that carpets the water surface with long-stalked heart-shaped leaves. The showy five-petaled yellow flowers occur on long stalks and rise a few inches above the water. It is a native of Eurasia and the Mediterranean area as well as Japan, China, and India and has been introduced into Washington, particularly along the Spokane River near Spokane. There is speculation that nurseries sold Yellow floating heart as an ornamental water plant because of its attractive yellow flowers and floating leaves.

It negatively affects fish and wildlife habitat, recreation activities and water quality. This floating-leaved plant grows in dense patches, excluding native species and creating stagnant areas with low oxygen levels underneath the floating mats. These mats make it difficult to fish, water ski, swim or paddle a canoe through.

The plant spreads by seeds and vegetatively. Seed hairs help the seeds float and aid their attachment to waterfowl, which can be a vector in spreading this plant to new areas.

The Washington State Noxious Weed Control Board listed Yellow floating heart as a Class B noxious weed in 2001. The Washington Department of Agriculture prohibits its sale, trade, and transport in Washington.

Class C Noxious Weeds – control is not required, but is recommended

Fragrant water lily (Nymphaea odorata)

This noxious weed is native to the eastern half of North America. It was probably introduced into Washington during the Alaska Pacific Yukon Exposition in Seattle in the late 1800's. It has often been introduced to ponds and lakes because of its beautiful, large white or pink (occasionally light yellow), many-petaled flowers that float on the water's surface, surrounded by large, round green leaves. The leaves are attached to flexible underwater stalks rising from thick fleshy rhizomes. Adventitious roots attach the horizontal creeping and branching rhizomes.

This aquatic perennial herb spreads aggressively, rooting in murky or silty sediments in water up to 7 feet deep. It prefers quiet waters such as ponds, lake margins and slow streams and will grow in a wide range of pH. Shallow lakes are particularly vulnerable to being totally covered by Fragrant water lilies. Water lily spreads by seeds and by rhizome fragments. A planted rhizome will cover about a 15-foot diameter circle in five years (Washington State Noxious Weed Control Board, 2001b). This can reduce the important open water component in the littoral zone of Lake Osoyoos.

When uncontrolled, this species tends to form dense mono-specific stands that can persist until senescence in the fall. Mats of these floating leaves prevent wind mixing and extensive areas of low oxygen can develop under the water lily beds in the summer. Water lilies can restrict lakefront access and hinder swimming, boating, and other recreational activities. Fragrant water lily infestations are growing increasingly dense in the lower portion of Lake Osoyoos. Recreational activities such as boating, fishing, and swimming will become more difficult. Even canoes can have great difficulty moving across dense floating mats of Fragrant water lily, not to mention entanglement with propellers of boat motors.

Yellow flag iris (Iris pseudacorus)

Yellow flag iris is native to mainland Europe, the British Isles, and the Mediterranean region of North Africa (Washington State Noxious Weed Control Board, 2001a). This plant was introduced widely as a garden ornamental and has been used for erosion control. The earliest collection in Washington is from Lake McMurray in Skagit County in 1948 (Washington State Noxious Weed Control Board, 2001a). The yellow flowers are a distinguishing characteristic, but when not blooming, it may be confused with Cattail (Typha sp.) or Broad-fruited bur-reed (Sparganium eurycarpum).

Yellow flag iris spreads by both rhizomes and seeds. The plants produce large fruit capsules and corky seeds in the late summer; these seeds are then easily dispersed along the water channel. Rhizomes may connect several hundred flowering plants. Yellow flag iris can spread to form dense stands that can exclude even the toughest of our native wetland species, such as Typha latifolia (cattail). This noxious weed has already infested a large area at the south end of the lake and threatens to disperse further up into the wetland if not controlled. In addition to decreasing plant diversity, Yellow flag iris can also alter hydrologic dynamics through sediment accretion along the shoreline. It has been observed in the Okanogan River, both south of Lake Osoyoos and at the delta of the Columbia River.

Japanese eelgrass (Zostera japonica)

The State Noxious Weed Control Board indicates that Japanese eelgrass is non-native, difficult to control and negatively impacts the shellfish industry. It was listed in 2012 as a Class C noxious weed on commercially managed shellfish beds only. In 2013, the modified wording was removed so that Japanese eelgrass is now a Class C noxious weed.

Nonnative cattail sp & hybrids
Cattail hybrids, Narrow-leaf cattail, Southern cattail, Small reed mace, Reed mace, Flags, Bulrushes, Cat o'nine tails, Cossack asparagus, and Baco are all common names for cattails, which were added to the State Noxious Weed list in 2014. Non-native and hybrid species can often be confused with Washington's only native species, *Typha latifolia*, also known as broad-leaved cattail or common cattail. Generally, there is a gap in the flowers of nonnative cattail species and hybrids between the male and female flowers while our native cattail typically does not have a gap. In addition, native cattail leaves are generally wider than nonnative species and hybrids' leaves.

Nonnative cattail species and hybrids grow in wet or saturated soils and aquatic sediments in marshes, wet meadows, lakeshores, pond margins, seacoast estuaries, ditches, bogs and fens. They can invade managed and recreation aquatic systems including canals, ditches, reservoirs, cultivated fields, farm ponds and swimming and boating areas.

Nonnative Typhas have been documented for their invasiveness and distribution in Washington is still limited but the documentation of new infestations is increasing.

Reed canarygrass (Phalaris arundinacea)
Canarygrass out competes most native species as it forms large, single-species stands, outcompeting other vegetation. Dense stands have little wildlife habitat value. Its invasion can cause siltation in irrigation ditches.

A highly variable species, Reed canarygrass is a rhizomatous, perennial, cool season grass that can reach three to six feet in height. It forms dense monotypic stands in wetland ecosystems. It can spread by seeds or by creeping rhizomes. The species will also produce roots and shoots from the nodes of freshly cut stems.

The species grows so vigorously that it is able to inhibit and eliminate competing species (Apfelbaum and Sams 1987). In addition, areas that have existed as Reed canarygrass monocultures for extended periods may have seed banks that are devoid of native species (Apfelbaum and Sams 1987). Unlike native wetland vegetation, dense stands of Reed canarygrass have little value for wildlife; the stems grow too densely to provide adequate cover for small mammals and waterfowl (Maia 1994). When in flower, the species produces abundant pollen and chaff, which aggravate hay fever and allergies (Weinmann et al. 1984).

While on the State Noxious Weed list and having detrimental impacts to riparian areas, this grass does provide important forage for many farmers and ranchers in Okanogan County. It is also used to provide some erosion control along streambanks.

Russian olive (Elaeagnus angustifolia)
Russian olive spreads along waterways and has naturalized along many of our major rivers in the interior western U.S. It can crowd out important native riparian plant communities that provide valuable wildlife habitat. Listed as a noxious weed in many other states, Russian olive is growing and spreading in eastern Washington.

It is a deciduous multi-stem shrub or tree, growing up to around 20 feet. It is a nitrogen-fixing plant with spiny stems, silvery foliage, fragrant yellow flowers and forms olive-like fruit. Plants primarily reproduce from seed. Seed dispersal occurs during the fall and winter, primarily by birds, other vertebrates and possibly water and ice. Cut trees can readily resprout from the crown and roots.

Its broad tolerance of environmental conditions can allow Russian olive to establish in conditions not suitable for native plant establishment. It can establish beneath the canopy of native riparian trees and form self-replacing stands. Reynolds and Cooper (2010) found Russian olive survival to be significantly higher in dense shade and low moisture conditions than native cottonwood. It can germinate and have seedlings survive in shade and in areas where flooding does not occur, allowing it to spread and invade further than its current distribution (Reynolds and Cooper 2010). Reynolds and Cooper (2010) found *Russian olive* establishing up to 8 meters above the stream channel in riparian zones where flooding cannot occur and soils only received precipitation. It may alter successional dynamics of riparian forests (Katz and Shafroth 2003). Much of the interior native riparian forests were dominated by native, pioneer species--primarily cottonwood and willow species—that rely on physical disturbance to create bare, moist patches for seedling establishment. These pioneer species are generally intolerant of shade and will not germinate or establish within shade. Seeds can germinate and survive in shade and are also viable longer than *Populus* and *Salix* species (Reynolds and Cooper 2010, Katz and Shafroth 2003). In the absence of physical disturbance, riparian forests eventually succeed to non-forested communities such as prairie or sagebrush steppe.

Tree of Heaven (Ailanthus altissima)
Naturalized throughout Washington, Tree of heaven is a fast growing tree, forming thickets that outcompete native plants. It leaches a variety of allelochemicals into the soil that have demonstrated inhibitory or toxic effects on neighboring plants. Along with its allelopathic effects, this species is believed to also suppress native vegetation by competition, as it can rapidly form clonal thickets.

It is a deciduous tree that grows to heights of 30 to 40 feet (though sometimes larger). Trees have compound, alternate leaves and clusters of male or female flowers. Plant parts have a distinct peanut butter or popcorn smell.

Plants can reproduce by seed as well as vegetatively by roots and stump sprouts. Cut branches and trees can also form roots when left on moist ground. It grows in a variety of habitats. It can commonly be found along forest edges, woodlands, fencerows, roadsides, railroad embankments, old fields, and urban parks.

Tree of heaven requires a lot of maintenance in urban green spaces and along roadsides due to their vegetative regeneration and fast growth. Stands may obstruct roadside vistas and become a safety hazard by blocking the view of drivers (Burch and Zedaker 2003). Also, tree roots may break asphalt surfaces (Danin 2000) and grow into wells and sewer lines (Hu 1979). Root suckers may sprout up into fields or other areas where trees are unwanted (Miller 1990).

AQUATIC PLANT CONTROL ALTERNATIVES

This section outlines common methods used to control aquatic weeds. Much of the information in this section is quoted directly from the Ecology's website:
http://www.ecy.wa.gov/programs/wq/plants/management/index.html

Additional information is derived from the field experience of the Okanogan County Noxious Weed Control Board, qualified WSDA licensed aquatic herbicide applicators, and conversations with WDFW and DNR aquatic specialists regarding various non-chemical control methods.

Control/eradication methods discussed herein include Aquatic Herbicide, Manual Methods, Bottom Screens, Diver Dredging, Biological Control, Rotovation, Cutting, Harvesting, and Drawdown.

AQUATIC HERBICIDES

Aquatic herbicides are chemicals specifically formulated for use in water to eradicate or control aquatic plants. Herbicides approved for aquatic use by the United States Environmental Protection Agency (EPA) have been reviewed and considered compatible with the aquatic environment when used according to label directions. However, individual states may also impose additional constraints on their use.

Aquatic herbicides are sprayed directly onto floating or emergent aquatic plants, or are applied to the water in a liquid or pellet form. Systemic herbicides are capable of killing the entire plant by translocation from the foliage or stems and killing the root. Contact herbicides cause the parts of the plant in contact with the herbicide to die back, leaving the roots alive and capable of re-growth (chemical mowing). Non-selective herbicides will generally affect all plants that they are exposed to, both monocots and dicots. Selective herbicides will affect only some plants (usually dicots – broad leafed plants like Eurasian watermilfoil will be affected by selective herbicides whereas monocots like Brazilian elodea and our native pondweeds may not be affected).

Because of environmental risks from improper application, aquatic herbicide use in Washington State waters is regulated and has certain restrictions. The Washington State Department of Agriculture must license aquatic applicators. In addition, because of a March 2001 court decision (Federal 9th Circuit District Court), coverage under a discharge permit called a National Pollutant Discharge Elimination System (NPDES) permit must be obtained before aquatic herbicides can be applied to some waters of the U.S. This ruling, referred to as the Talent Irrigation District decision, has further defined Section 402 of the Clean Water Act. Ecology has developed a general NPDES permit, which is available for coverage under the Washington Department of Agriculture for the management of noxious weeds growing in an aquatic situation and a separate general permit for nuisance aquatic weeds (native plants) and algae control. For nuisance weeds (native species also referred to as beneficial vegetation) and algae, applicators and the local sponsor of the project must obtain a NPDES permit from the Washington Department of Ecology before applying herbicides to Washington water bodies.

OCNWCB has obtained these permits, both from WSDA and DOE, for several bodies of water. Further bodies of water will be included in these permits upon request from shoreline owners or need to control required species of vegetation.

Aquatic Herbicides Labeled for use in Washington State (see Appendix E for specific herbicide labels) based on active ingredient. Please realize that different companies will provide these herbicide formulations under various trade names. To avoid confusion and displays of favoritism, we are only discussing active ingredients below.

DOE has risk assessments for these herbicides available at
http://www.ecy.wa.gov/programs/wq/pesticides/seis/risk_assess.html and a full list of available herbicides and adjuvants are available at
http://www.ecy.wa.gov/programs/wq/pesticides/regpesticides.html

Additional surfactants are always added by the applicator for the aquatic formulations to improve the penetration of the leaf cuticle and help the herbicide stay on the plant long enough to be effective. Those that may be used for emergent weed control include X-77, LI-700, and R-11 as approved by the SEPA process. Only LI-700 is approved for Fragrant water lily control under the NPDES permit. There are a number of adjuvants (surfactants, stickers, sinking agents) allowed for use under the NPDES permits.

Aquatic labeled Glyphosate - This systemic nonselective herbicide is used to control floating-leaved plants like Water lilies and shoreline plants like Purple loosestrife and Yellow flag iris. It is generally applied as a liquid to the leaves. It does not work on underwater plants such as Eurasian watermilfoil. Although glyphosate is a non-selective herbicide, a good applicator can somewhat selectively remove targeted plants by focusing the spray only on the plants to be removed. Plants take several weeks to die. A repeat application is often necessary to remove plants that were missed during the first application. **Note**: there are now several glyphosate products available, but with different trade names now that the patent has expired.

Aquatic labeled 2,4-D – There are two formulations of 2,4-D approved for aquatic use. The granular formulation contains the low-volatile butoxy-ethyl-ester formulation of 2,4-D. The liquid formulation contains the dimethylamine salt of 2,4-D. It is a relatively fast-acting, systemic, selective herbicide used for the control of Eurasian watermilfoil and other broad-leaved species. Both the granular and liquid formulations can be effective for spot treatment of Eurasian watermilfoil. 2,4-D has been shown to be selective to Eurasian watermilfoil when used at the labeled rate, leaving native aquatic species relatively unaffected. By court-order the butoxy-ethyl-ester formulation of 2,4-D cannot be used in waters with threatened and endangered salmon-bearing waters in the Pacific Northwest.

Aquatic labeled Fluridone - is a slow-acting systemic herbicide used to control Eurasian watermilfoil and other underwater plants. It may be applied in pelleted form or as a liquid. Fluridone can show good control of submersed plants where there is little water movement and an extended time for the treatment. Its use is most applicable to whole-lake or isolated bay treatments where dilution can be minimized. It is not effective for spot treatments. It may take six to twelve weeks before the dying plants fall to the sediment and decompose. When used to manage Eurasian watermilfoil, fluridone is applied several times during the summer to maintain a low, but consistent concentration in the water. Although fluridone is considered a non-selective herbicide, when used at low concentrations, it can be used to selectively remove Eurasian watermilfoil. Some native aquatic plants, especially pondweeds, are minimally affected by low concentrations of fluridone.

Aquatic Labeled Endothall - Endothall is a fast-acting non-selective contact herbicide which destroys the vegetative part of the plant but generally does not kill the roots. Endothall may be applied in a granular or liquid form. Typically, endothall compounds are used primarily for short term (one season) control of a variety of aquatic plants. However, there has been some recent research that indicates that when used in low concentrations, endothall can be used to selectively remove exotic weeds; leaving some native species unaffected. Because it is fast acting, endothall can be used to treat smaller areas effectively. Endothall is not effective in controlling Canadian waterweed (*Elodea canadensis*) or Brazilian elodea.

Aquatic labeled Diquat - Diquat is a fast-acting non-selective contact herbicide, which destroys the vegetative part of the plant but does not kill the roots. It is applied as a liquid. Typically, diquat is used primarily for short-term (one season) control of a variety of submersed aquatic plants. It is very fast acting and is suitable for spot treatment. However, turbid water or dense algal blooms can interfere with its effectiveness. Diquat was allowed for use in Washington in 2003 and Ecology collected information about its efficacy against Brazilian elodea in 2003. A littoral zone treatment in Battle Ground Lake in Clark County Washington in 2003 resulted in nearly complete removal of Brazilian elodea in that water body.

Aquatic lableled Triclopyr-TEA - There are two formulations of triclopyr. It is the TEA formation of triclopyr that is registered for use in aquatic or riparian environments. Triclopyr, applied as a liquid, is a relatively fast-acting, systemic, selective herbicide used for the control of Eurasian watermilfoil and other broad-leaved species such as Purple loosestrife. Triclopyr can be effective for spot treatment of Eurasian watermilfoil and is relatively selective to Eurasian watermilfoil when used at the labeled rate. Many native aquatic species are unaffected by triclopyr. Triclopyr is very useful for Purple loosestrife control since native grasses and sedges are unaffected by this herbicide. When applied directly to water, Ecology has imposed a 12-hour swimming restriction to minimize eye irritation. Triclopyr received its aquatic registration from EPA in 2003 and was allowed for use in Washington in 2004.

Aquatic labeled Imazapyr - This systemic broad spectrum, slow-acting herbicide, applied as a liquid, is used to control emergent plants like Spartina, Reed canarygrass, and Phragmites and floating-leaved plants like Water lilies. Imazapyr does not work on underwater plants such as Eurasian watermilfoil. Although imazapyr is a broad spectrum, non-selective herbicide, a good applicator can somewhat selectively remove targeted plants by focusing the spray only on the plants to be removed. Imazapyr was allowed for use in Washington in 2004.

Advantages

- Aquatic herbicide application can be less expensive and more effective than other aquatic plant control methods.
- Aquatic herbicides are easily applied around docks and underwater obstructions.
- 2,4-D DMA & 2,4-D BEE have been shown to be effective in controlling smaller infestations (not lake-wide) of Eurasian watermilfoil in Washington, and could also be used on the Purple loosestrife and Yellow flag iris.
- Washington has had some success in eradicating Eurasian watermilfoil from some smaller lakes (320 acres or less) using fluridone.
- Glyphosate is the recommended chemical for Fragrant water lily control.

Disadvantages

- Generally, most aquatic herbicides have use restrictions, with irrigation restrictions being the most common. Some herbicides have swimming, drinking, fishing, irrigation, and water use restrictions.
- Herbicide use may have unwanted impacts to people who use the water and to the environment.
- Non-targeted plants as well as nuisance plants may be controlled or killed by some herbicides.
- Depending on the herbicide used, it may take several days to weeks or several treatments during a growing season before the herbicide controls or kills treated plants.
- Rapid-acting herbicides may cause low oxygen conditions to develop as plants decompose. Low oxygen can cause fish kills.
- To be most effective, generally herbicides must be applied to rapidly growing plants.
- As with any pesticide, some expertise in using herbicides is necessary in order to be successful and to avoid unwanted impacts.
- Many people have strong feelings against using chemicals in water.
- Some cities or counties may have policies forbidding or discouraging the use of aquatic herbicides.

Permits

The Aquatic Noxious Weed Management General Permit regulates the use of pesticides and other products applied to manage Washington State listed noxious weeds and Washington State quarantine-listed weeds where pesticides or other products may **indirectly** enter the surface waters of the state of Washington. The permit covers all marine and freshwater activities that result in a discharge of herbicides, adjuvants, and marker dyes (collectively chemicals) indirectly into streams, rivers, estuaries, marine areas, wetlands, along lake shorelines, and other wet areas. The permit also covers the treatment of noxious- and quarantine-listed vegetation for roadside/ditch bank management activities where chemicals may indirectly enter the water. The permit covers only the chemical management of plants. This permit is issued by Washington State Dept. of Agriculture and OCNWCB currently has Limited Agent Status coverage for Okanogan County waters.

The Aquatic Plant and Algae Management General Permit is needed to treat vegetation by **direct** application to the water. The permit covers both noxious and nuisance plants. OCNWCB has current coverage for Palmer, Osoyoos and Spectacle Lakes and will apply for further coverage as needed or desired to control aquatic noxious and nuisance plants.

Both the Aquatic Noxious Weed Management and Aquatic Plant and Algae NPDES permits require the development of Integrated Aquatic Vegetation Management Plans (IAVMP) by the third year of control work.

Monitoring of herbicide levels in the water may be required, whether the chemical has been applied directly to the water or along the shoreline where it may have gotten into the adjacent water.

Costs

Costs associated with chemical control of aquatic weeds will vary by site, timing and the chemical used. Generally, costs will be between $200 and $1,500 per acre depending on elements included in the application, such as notifications and advertising, as well as the actual cost of the application. OCNWCB will continue to hold the permits necessary for chemical treatment, reducing control costs countywide.

MANUAL METHODS

Hand Pulling

Hand pulling of aquatic plants is similar to pulling weeds out of a garden. It involves removing entire plants (leaves, stems, and roots) from the area of concern and disposing of them in an area away from the shoreline. In water less than three feet deep no specialized equipment is required, although a spade, trowel, or long knife may be needed if the sediment is packed or heavy. In deeper water, hand pulling is best accomplished by divers with SCUBA equipment and mesh bags for the collection of plant fragments. Some sites may not be suitable for hand pulling such as areas where deep flocculent sediments may cause a person hand pulling to sink deeply into the sediment.

Cutting

Cutting differs from hand pulling in that plants are cut and the roots are not removed. Cutting is performed by standing on a dock or on shore and throwing a cutting tool out into the water. A non-mechanical aquatic weed cutter is commercially available. Two single-sided, razor sharp stainless steel blades forming a “V” shape are connected to a handle, which is tied to a long rope. The cutter can be thrown about 20 – 30 feet into the water. As the cutter is pulled through the water, it cuts a 48-inch wide swath. Cut plants rise to the surface where they can be removed. Washington State requires that cut plants be removed from the water. The stainless steel blades that form the V are extremely sharp and great care must be taken with this implement. It should be stored in a secure area where children do not have access.

Raking

A sturdy rake makes a useful tool for removing aquatic plants. Attaching a rope to the rake allows removal of a greater area of weeds. Raking literally tears plants from the sediment, breaking some plants off and removing some roots as well. Specially designed aquatic plant rakes are available. Rakes can be equipped with floats to allow easier plant and fragment collection. The operator should pull towards the shore because a substantial amount of plant material can be collected in a short distance.

Cleanup
All of the manual control methods create plant fragments. It's important to remove all fragments from the water to prevent them from re-establishing or drifting onshore. Plants and fragments can be composted or added directly to a garden.

Advantages
- Manual methods are easy to use around docks and swimming areas.
- The equipment is inexpensive.
- Hand pulling allows the flexibility to remove undesirable aquatic plants while leaving desirable plants.
- These methods are environmentally safe.
- Manual methods do not require expensive permits, and can be performed on aquatic noxious weeds with Hydraulic Project Approval obtained by reading and following the pamphlet *Aquatic Plants and Fish* (publication #APF-1-98) available from the Washington Department of Fish & Wildlife.

Disadvantages
- As plants re-grow or fragments re-colonize the cleared area, the treatment may need to be repeated several times each summer.
- Because these methods are labor intensive, they may not be practical for large areas or for thick weed beds.
- Even with the best containment efforts, it is difficult to collect all plant fragments, leading to re-colonization.
- Some plants, like water lilies, which have massive rhizomes, are difficult to remove by hand pulling.
- Pulling weeds and raking stirs up the sediment and make it difficult to see remaining plants. Sediment re-suspension can also increase nutrient levels in lake water.
- Hand pulling and raking impacts bottom-dwelling animals.
- The V-shaped cutting tool is extremely sharp and can be dangerous to use.

Permits
Permits are required for many types of manual projects in lakes and streams. The Washington State Department of Fish and Wildlife requires a *Hydraulic Project Approval* permit for all activities taking place in the water including hand pulling, raking, and cutting of aquatic plants. The permit is available at http://wdfw.wa.gov/licensing/aquatic_plant_removal/ and there is no associated fee. It is also included as Appendix F of this IAVMP.

Costs
- Hand pulling costs up to $130 for the average waterfront lot for a hired commercial puller.
- A commercial grade weed cutter costs about $130 with accessories. A commercial rake costs about $95 to $125. A homemade weed rake costs about $85 (asphalt rake is about $75 and the rope costs 35-75 cents per foot).

Other Considerations
Does the community want to invest in weed rakes, other equipment? Manual methods must include regular scheduled surveys to determine the extent of the remaining weeds and/or the appearance of new plants after eradication has been attained.

BOTTOM BARRIERS

A bottom screen or benthic barrier covers the sediment like a blanket, compressing aquatic plants while reducing or blocking light. Materials such as burlap, plastics, perforated black Mylar, and woven synthetics can all be used as bottom screens. Some people report success using pond liner materials.

An ideal bottom screen should be durable, heavier than water, reduce or block light, prevent plants from growing into and under the fabric, be easy to install and maintain, and should readily allow gases produced by rotting weeds to escape without "ballooning" the fabric upwards. Even the most porous materials, such as window screen, will billow due to gas buildup. Therefore, it is very important to anchor the bottom barrier securely to the bottom. Unsecured screens can create navigation hazards and are dangerous to swimmers. Anchors must be effective in keeping the material down and must be regularly checked. Natural materials such as rocks or sandbags are preferred as anchors.

The duration of weed control depends on the rate that weeds can grow through or on top of the bottom screen, the rate that new sediment is deposited on the barrier, and the durability and longevity of the material. For example, burlap may rot within two years; plants can grow through window screening material, and can grow on top of felt-like fabric. Regular maintenance is essential and can extend the life of most bottom barriers.

Bottom screens will control most aquatic plants; however freely floating species such as the Bladderworts or Coontail will not be controlled by bottom screens. Plants like Eurasian watermilfoil will send out lateral surface shoots and may canopy over the area that has been screened giving less than adequate control.

In addition to controlling nuisance weeds around docks and in swimming beaches, bottom screening has become an important tool to help eradicate and contain early infestations of noxious weeds such as Eurasian watermilfoil and Brazilian elodea. Pioneering colonies that are too extensive to be hand pulled can sometimes be covered with bottom screening material. For these projects, we suggest using burlap with rocks or burlap sandbags for anchors. By the time the material decomposes, the milfoil patches will be dead as long as all plants were completely covered. Snohomish County staff reported native aquatic plants colonizing burlap areas that covered pioneering patches of Eurasian watermilfoil. When using this technique for Eurasian watermilfoil eradication projects, divers should recheck the screen within a few weeks to make sure that all milfoil plants remain covered and that no new fragments have taken root nearby.

Advantages

- Installation of a bottom screen creates an immediate open area of water.
- Bottom screens are easily installed around docks and in swimming areas.
- Properly installed bottom screens can control up to 100 percent of aquatic plants.
- Screen materials are readily available and can be installed by homeowners or by divers.

Disadvantages

Because bottom screens reduce habitat by covering the sediment, they are suitable only for localized control.

- For safety and performance reasons, bottom screens must be regularly inspected and maintained.
- Harvesters, rotovators, fishing gear, propeller backwash, or boat anchors may damage or dislodge bottom screens.
- Improperly anchored bottom screens may create safety hazards for boaters and swimmers.

- Swimmers may be injured by poorly maintained anchors used to pin bottom screens to the sediment.
- Some bottom screens are difficult to anchor on deep muck sediments.
- Bottom screens interfere with fish spawning and bottom-dwelling animals.
- Without regular maintenance, aquatic plants may quickly colonize the bottom screen.

Permits
Bottom screening in Washington requires a Hydraulic Project Approval pamphlet, and may require additional approval obtained from the WDFW. Check with your local jurisdiction to determine whether a shoreline permit is required.

Costs
Barrier materials cost $0.22 to $1.25 per square foot. The cost of some commercial barriers includes an installation fee. Commercial installation costs vary depending on sediment characteristics and type of bottom screen selected. It costs up to about $750 to have 1,000 square feet of bottom screen installed. Maintenance costs for a waterfront lot are about $120 each year.

DIVER DREDGING
Diver dredging (suction dredging) is a method whereby SCUBA divers use hoses attached to small dredges (often dredges used by miners for mining gold from streams) to suck plant material from the sediment. The purpose of diver dredging is to remove all parts of the plant including the roots. A good operator can accurately remove target plants, like Eurasian watermilfoil, while leaving native species untouched. The suction hose pumps the plant material and the sediments to the surface where they are deposited into a screened basket. The water and sediment are returned back to the water column (if the permit allows this) and the plant material is retained. The turbid water is generally discharged to an area curtained off from the rest of the lake by a silt curtain. The plants are disposed of on shore. Removal rates vary from approximately 0.25 acres per day to one acre per day depending on plant density, sediment type, and diver efficiency.

Diver dredging is more effective where softer sediment allows easy removal of the entire plants, although water turbidity is increased with softer sediments. Harder sediment may require the use of a knife or tool to help loosen sediment from around the roots. In very hard sediments, milfoil plants tend to break off leaving the roots behind and defeating the purpose of diver dredging.

Diver dredging has been used in British Columbia, Washington, and Idaho to remove early infestations of Eurasian watermilfoil. In a large scale operation in western Washington, two years of diver dredging reduced the population of milfoil by 80 percent. Diver dredging is less effective on plants where seeds, turions, or tubers remain in the sediments to sprout the next growing season. For that reason, Eurasian watermilfoil is generally the target plant for removal during diver dredging operations.

Advantages
- Diver dredging can be a very selective technique for removing pioneer colonies of Eurasian watermilfoil.
- Divers can remove plants around docks and in other difficult to reach areas.
- Diver dredging can be used in situations where herbicide use is not an option for aquatic plant management.

Disadvantages
- Diver dredging is very expensive.
- Dredging stirs up sediments. This may lead to the release of nutrients or long-buried toxic materials into the water column.

- The tops of plants growing in rocky or hard sediments may be removed, leaving a viable root crown behind to initiate growth.
- In some states, acquisition of permits can take years.

Permits

Diver dredging requires an HPA from WDFW. Diver dredging cannot be conducted in Lake Osoyoos without additional prior authorization by WDFW, due to potential impact to sockeye spawning areas. Diver dredging may require a Section 404 permit from the U.S. Army Corps of Engineers. Check with them before starting the project. Also, check with your city or county for any local requirements before proceeding with a diver-dredging project.

Costs

Depending on the density of the plants, specific equipment used, and disposal requirements, costs can range from a minimum of $1,500 to $2,000 per day.

BIOLOGICAL CONTROL

Bio control agents have been historically used in Okanogan County for control of Purple Loosestrife. While the agents are effective, the minor fluctuations in water level do not readily contribute to establishment of weevil populations. Ongoing and continual releases have shown some effective control.

The native Northern watermilfoil is the intended host for the milfoil weevil (Euhrychiopsis lecontei). However, this weevil has shown a preference for the non-native Eurasian watermilfoil. While the weevil is established in at least two lakes in Okanogan County, it is not present in densities necessary to control E. milfoil. ***This weevil is available for purchase outside of Washington State, but concerns about the spread of other aquatic species make this source unavailable in Washington. Do not attempt to purchase and release this weevil from out of state.***

In 2012, the Lake Osoyoos Association (LOA), with assistance from DOE, initiated a pilot project to establish rearing guidelines allowing propagation of weevils by interested parties. The pilot project consisted of purchasing the necessary equipment, tanks, aerators, etc., collecting weevils and sufficient E. milfoil to provide habitat and food source, and following the progress in the local high school science lab. The weevils, including progeny were released into the lake in 3 weeks. LOA revisited the release site to monitor any results from the re-introduction and noted a definite lowering of milfoil stems in the water column.

A collection of weevils occurred along the shoreline in early spring with encouraging results. A berlaise funnel was used to separate the weevils from shoreline debris. These weevils were not introduced into water, however, and further study of this collection method is necessary to provide information regarding weevil survival and overwintering habits.

Grass carp have been suggested for use in milfoil control efforts, but the lack of specificity may lead to declines in native vegetation that would use nutrients in the lake, and provide competition for resources by the E. milfoil.

Advantages

- Bio control methods are long term, providing some level of control.
- The agents are inexpensive, once approved for re-distribution through APHIS, or native as in the case of the milfoil weevil.
- These methods are environmentally safe, with minimal or no effect on off target species.

Disadvantages

- Bio controls are not effective at eradication efforts.
- They take a significant amount of time to become established at densities needed to provide sufficient control.
- They are expensive to get approved through APHIS for initial release.

Permits

Once approved through APHIS and DOE, no permits are needed for approved bio-control releases.

Costs

- Approximately $120 to set up equipment to rear E. milfoil weevils, though the collection process is very time consuming.
- At this time Purple loosestrife bio controls are distributed at no charge through a partnership with WSU Extension. However, should that aspect change, bio controls are typically available for approx. $1/agent.

MECHANICAL

Harvesting and rototilling are options frequently used for aquatic vegetation control efforts. Both methods are used on the Canadian side of the lake to control non-native milfoil infestations.

Mechanical harvesters are large machines, which both cut and collect aquatic plants. Cut plants are removed from the water by a conveyor belt system and stored on the harvester until disposal. A barge may be stationed near the harvesting site for temporary plant storage or the harvester carries the cut weeds to shore. The shore station equipment is usually a shore conveyor that mates to the harvester and lifts the cut plants into a dump truck. Harvested weeds are disposed of in landfills, used as compost, or in reclaiming spent gravel pits or similar sites.
Harvesting is usually performed in late spring, summer, and early fall when aquatic plants have reached or are close to the water's surface. Harvesters can cut and collect several acres per day depending on weed type, plant density, and storage capacity of the equipment. Harvesting speeds for typical machines range from 0.5 to 1.5 acres per hour. Depending on the equipment used, the plants are cut from five to ten feet below the water's surface in a swath 6 to 20 feet wide. Some modern harvesters can cut plants in a range of water depths. Because of machine size and high costs, harvesting is most efficient in lakes larger than a few acres. Harvesting can be an excellent way to create open areas of water for recreation and fishing access.

Along with plants, harvesters also collect a large number of small fish and invertebrates. Amphibians and turtles have been known to be collected as well.

Advantages

- Harvesting results in immediate open areas of water.
- Removing plants from the water removes the plant nutrients, such as nitrogen and phosphorus, from the system.
- Harvesting as aquatic plants are dying back for the winter can remove organic material and help slow the sedimentation rate in a waterbody.
- Since the lower part of the plant remains after harvest, habitat for fish and other organisms is not eliminated.
- Harvesting can be targeted to specific locations, protecting designated conservancy areas from treatment.

Disadvantages

- Harvesting is similar to mowing a lawn; the plant grows back and may need to be harvested several times during the growing season.
- There is little or no reduction in plant density with mechanical harvesting.
- Off-loading sites and disposal areas for cut plants must be available. On heavily developed shorelines, suitable off-loading sites may be few and require long trips by the harvester.
- Some large harvesters are not easily maneuverable in shallow water or around docks or other obstructions.
- Significant numbers of small fish, invertebrates, and amphibians are often collected and killed by the harvester.
- Harvesting creates plant fragments, which may increase the spread of invasive plant species such as Eurasian watermilfoil throughout the waterbody.
- Although harvesters collect plants as they are cut, not all plant fragments or plants may be picked up. These may accumulate and decompose on shore, often forming new infestations.
- Harvesters are expensive and require routine maintenance.
- Harvesting may not be suitable for lakes with many bottom obstructions (stumps, logs) or for very shallow lakes (3-5 feet of water) with loose organic sediments.
- Harvesters brought into the waterbody from other locations need to be thoroughly cleaned and inspected before being allowed to launch. Otherwise, new exotic species could be introduced to the waterbody.

Permits

Harvesting in Washington requires hydraulic approval from the Department of Fish and Wildlife. Some Shoreline Master Programs may also require permits for harvesting, but in Okanogan County, that is not the case. Because harvesting collects fish along with aquatic plants, some additional monitoring may be required when harvesting in salmon bearing waters.

Costs

Costs per acre vary with numbers of acres harvested, accessibility of disposal sites to the harvested areas, density and species of the harvested plants, and whether a private contractor or public entity does the work. Private contractors generally charge $500 to $800 per acre. The purchase price of harvesters ranges from $35,000 to $110,000. There are several harvester manufacturers in the United States and some lake groups may choose to operate and purchase their own machinery rather than contracting for these services.

Rotovation

A rotovator is a barge-mounted rototilling machine that lowers a tiller head about eight to ten inches into the sediment to dislodge milfoil root crowns. The mechanical agitation produced by the tiller blades dislodges the root crowns from the sediment and the buoyant root masses float to the water surface. Since the entire plant is removed, plant biomass remains reduced in the treatment area throughout the growing season and often longer. Rotovation often provides two full seasons of control (Gibbons et. al, 1987). Unlike harvesters, rotovators do not have the capability to collect the plants.

Rotovation is a way to mechanically remove milfoil to provide open areas of water for recreational activities and navigation. Waterbodies suitable for rotovation include larger lakes or rivers with widespread, well-established milfoil populations where milfoil eradication is not an option. Since on-going rotovation programs are very expensive, having a large lake population or a motivated local government to share these costs is crucial. Because rotovation is expensive and multiple permits are needed, rotovation has not become a widespread milfoil control activity in Washington or elsewhere in the United States.

Rotovation is not recommended in water bodies with early infestations of milfoil since fragments are created and rotovation may increase the spread of milfoil throughout the waterbody. Because rotovation creates turbidity, rotovation may not be appropriate in salmon-bearing waters, although sometimes Fish and Wildlife staff are able to provide windows of time when rotovation activities will have the least impact on fish. Because rotovation and the resultant turbidity may affect the entire waterbody, it should be conducted under the direction of an integrated aquatic vegetation management plan.
Rotovation requires a Hydraulic Project Approval from Fish and Wildlife.

Factors to consider when designing a rotovation program include:
•Waterbody surface area, width, and depth.
•Vegetated acres.
•Bottom contours and bottom obstructions such as stumps, rocks, and other debris.
•Traffic patterns.
•Prevailing winds.
•Rotovator launching and off-loading sites.
•Sediment type.
•Shoreline development.
•Sensitive areas (critical habitat).

A waterbody committee and/or local government staff should identify acreages and areas to be rotovated. Priorities may be determined by who funds the program. A local government will be more interested in rotovating public areas, whereas local residents may be interested in rotovating areas in front their homes. However, generally high use areas such as public parks, community access points, navigation channels, public boat launches, and water ski lanes receive priority. Sometimes rotovators can be used to create fishing lanes in dense beds of milfoil to provide better fishing access to anglers.

Prior to rotovation, machinery launch sites (a paved ramp with deep water is best) need to be identified. Since rotovators do not collect plants as they work, a method for removing plants from the water should be developed. This may involve having a harvesting machine follow behind the rotovator to collect plants or hiring people to rake plants off beaches. Rotovation activities should begin at the farthest point up stream. The plants are then carried downstream and get caught up on the remaining dense milfoil beds.

During a rotovation project, the rotovator tilling head is lowered into the sediment and power is applied. The rotating head churns into the sediment dislodging milfoil root crowns and plants, and a plume of sediments. The rotovated plants eventually sink or wash up on shore and the sediments gradually settle from the water. Canadian plant managers have recorded milfoil stem density and root crown reductions of better than 99 percent after rotovation test trials (British Columbia Ministry of Environment memo dated 1991). Where repeated treatments have occurred at the same site over several consecutive years, treatment intervals may extend longer than two years (Gibbons, et. al, 1987).

In a few waterbodies such as in the Pend Oreille River, rotovation may be performed year-round. In most water bodies, timing is dependent on fish windows. Washington Fish and Wildlife does not want rotovation activities to take place when fish are spawning or juvenile salmon are migrating through the waterbody.

For efficacy of milfoil removal, it is best to begin operations in early spring and resume in the fall. Rotovation is less effective in the summer when the long milfoil plants wrap around the rotovating head, slowing down the operation. If rotovation occurs during the summer, it is more efficient to cut or harvest the plants beforehand. Weather creates winter rotovation delays, although it is possible to rotovate throughout the winter months (as long as the waterbody does not freeze). Delays in the rotovation schedule can result from high winds, thunderstorms, freezing water, and mechanical failure. There is a lot of maintenance and some down time on machinery working on the water.

Complaints about rotovation include increased plant fragments washing up along shorelines, and broken water intakes. It is important to establish some clear guidelines and policies to help make decisions and to settle disputes.

General impacts of rotovation:

- Rotovators stir sediments into the water column. In addition to the sediments, buried toxic materials and/or nutrients may be released.
- Generally, turbidity is short-term and the water returns to normal within 24 hours, but the length of time that sediments remain suspended depends on sediment type.
- Plants and root crowns are uprooted from the sediment and unless a plant removal plan is in place, these plants will either sink or be washed on shore.
- Rotovation appears to stimulate the growth of native aquatic plants. Whether this is due to the removal of milfoil, the action of the rotovator stimulating seed or propagule germination, or a combination of these factors is not known.
- Rotovators are also large machines with hydraulic systems and fuel that occasionally leaks or is spilled. The operator should have a spill plan and containment equipment on board for emergency use.

In 1987, Ecology conducted an evaluation of rotovation in Lake Osoyoos. This lake was chosen because it has a history of mining and agricultural use and therefore might represent a “worst case” scenario in terms of the potential for release of contaminants from sediment. The objectives of the study were to document effectiveness of rotovation by measuring changes in milfoil stem densities before and after treatment, and to assess impacts of rotovation on selected water quality parameters, benthic invertebrates, and the fisheries. Although the rotovator malfunctioned during the test (the hydraulic system driving the rototiller was not functioning properly), the results were consistent with data collected by the British Columbia Ministry of the Environment of sites rotovated by a fully operating rotovator. During the Lake Osoyoos rotovator test, rotovation appeared to have little impact on fish, water quality, or benthic invertebrates. However, during this test, milfoil stem densities were not reduced to the extent that should have occurred had the machinery been operating properly. Although the results indicated only short-term, impacts associated with rotovation, the test was faulty and it is difficult to draw firm conclusions. This study was not repeated.

CONCLUSION

The water bodies in Okanogan County include a lake and river that cross an international border, an inland saline lake, and myriad others that are home to a variety of fish, birds, and other wildlife. They offer a vast array of activities, such as fishing, boating and swimming and provide water for our agriculture. A vast array of shoreline lands incudes Federal, State and Private ownership. A variety of interests will drive the Integrated Aquatic Vegetation Management Plan. No one control method will work for every situation or noxious weed infestation. Therefore, we will use a truly integrated approach, using best management practices, and based upon the individual shore owners’ needs and the needs of the waters at individual sites.

While the main emphasis of control efforts will change from landowner to landowner, and waterbody to waterbody, the objective of all involved is to reduce infestations of aquatic noxious weeds. These noxious weeds must be reduced to levels that are tolerable and promote an increase functionality of habitat for fish and aquatic organisms. A safe environment for recreation and other uses of the lake including agriculture must be provided.

Eradication will be the primary goal for Class A species and control methods will be based on best management protocols for that individual species. Manual control methods will be utilized, if appropriate, on those infestations of extremely limited proportions where control can be achieved quickly with limited use of chemicals in our waters. Chemical control will occur to reduce the size and density of larger infestations following all label recommendations, rates, and timing windows. Federal and State partners in control efforts will not be permitted to treat outside their respective boundaries; therefore, the OCNWCB will take the lead and coordinate control activities to perform work across jurisdictions.

Many landowners have already begun chemical treatments to reduce the Eurasian watermilfoil infestations along their shore area under the permit held by OCNWCB. These activities have been performed by licensed applicators using the aquatic labeled herbicides available in Washington State. Restrictions were originally placed on the permit for Lake Osoyoos, disallowing herbicide use within a quarter mile of the international border. These restrictions remain in place at this time, and applications are limited to 100 acres. The Noxious Weed Board will continue to work with LOA to improve the water quality and limit continual re-infestation from Canadian control practices.

While the consensus our steering group reflects the ineffectiveness of a harvester for E. milfoil control, talks will continue with Canada to explore the possibility of utilizing their harvester south of the border in the buffer area. While the harvester will not effectively control the aquatic vegetation, it will allow for safer recreation and increased use of the lake.

Noxious weed infestations will be controlled, with a priority given to those weeds listed as Class A on the State Noxious Weed List, and those waterbodies with limited distribution of other mandatory control noxious weeds, using Early Detection, Rapid Response principles.

Okanogan Lakes Aquatic and Wetland Noxious Aquatic Weed Survey

Prepared for
Okanogan Conservation District

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Introduction

Okanogan County has been combating invasive aquatic plants for a number of years. The County Noxious Weed Department began targeting Purple Loosestrife in the 1980's with a combination of chemical and biological control efforts. Eurasian Milfoil has also been a significant problem in the regions lakes and the Department has facilitated control efforts in three of the major recreational lakes in the region.

Water based recreational opportunities provide a significant contribution to the economy of the region and protecting these resources is an important function of local government. The Department saw an opportunity to inventory the lakes and rivers within the County where public access was available in 2014. This report will summarize the survey performed on the public lakes within the County and discuss the findings and impacts of noxious aquatic weeds present.

Methods

The contract called for a visual survey of the littoral and riparian areas of the following lakes within Okanogan County:

- Sidley Lake
- Chopaka Lake
- Palmer Lake
- Whitestone Lake
- Conconully Lake
- Conconully Reservoir
- Omak Lake
- Leader Lake
- Pearygin Lake
- Patterson Lake
- Buffalo Lake
- Alta Lake
- Blue Lake
- Fish Lake
- Connors Lake
- Forde Lake

The first step that was conducted was an aerial shoreline analysis flight of all of the lakes on this list. This mission was conducted in late August after the award of the contract. The flight mission was conducted from Wenatchee Airport. The lake targets were plotted on the Seattle Sectional Chart and the team navigated to each of these. The team collected low level oblique photography of the littoral areas of each system.

The Geographic Information System Project file was then created to support the field mapping efforts. A point file was created for each lake that was to be the subject of the survey. These could be used to navigate to them and for general planning and discussion. A bathymetry layer was then used to help define the littoral zone of each lake and limit inspection to those areas. Aquatic plants can only grow to a water depth where light is available to support photosynthesis. Light becomes absorbed and extinct in water with depth. Generally aquatic plants will not survive at water depths below 20 feet because of light limitations and water pressure becomes a limiting factor at 28 feet for most species. The bathymetry information allowed the team to understand the exact shape and location of the littoral zone in each lake. Aquatic plant communities that were observed from the air were also placed onto the field survey maps.

The mapping team then mobilized to the County. The aerial image data was examined in the pre mapping briefing so each mapping team had a clear picture of conditions present in each lake prior to moving into the field. The team staged from Omak. Two LUND survey craft and a truck team equipped with a portable johnboat and motor were used for lakes where access was limited.

Each team utilized a data dictionary developed using the list of aquatic and riparian plants outlined in the RFP. The data dictionary was uploaded to Trimble Juno and Yuma data logging Global Positioning System (GPS) receivers. This hardware and software allows the team to locate and map positions with sub-meter accuracy and attached species attribute data to each feature.

Point features were collected in situations where individual plants were observed during the visual survey either in the water or on the shoreline riparian areas. A line features was collected from the boat parallel to shorelines where there was a sustained infestation of noxious wetland species present. A polygon feature was collected in situations on the water where a larger noxious aquatic plant bed was discovered.

This data was backed up at the end of each day. The survey teams met each evening, discussed the accomplishments and finding and made any necessary adaptations to the work flow. It took the four teams approximately one week to complete field efforts.

This data was then brought back to the mapping facility at headquarters. All of the Trimble data files were processed using Trimble Pathfinder software. The first step was to perform differential correction of the data files. This process accesses base station GPS data collected at the same time as the survey team was in the field and uses that data to correct position accuracy to within a foot or so. The corrected files were then exported as ESRI Shape files to ArcMap 10.2 and used to create the maps for the final report. The GPS data comes into ArcMAP as WGS 1984 projection. These were displayed on the ArcMAP project. We then created point and polygon features for each of the species found using a projection State Plane Projection to remove the error that can be present when calculating area in the WGS projection.

A map for each lake was generated for use in the results section of this report.

Results

This visual survey effort resulted in the detection and mapping of a number of species of noxious aquatic and wetland weed species. It should be noted that the specifications for this survey indicated that a visual inventory inspection of these lake littoral areas. While the team did perform a detailed visual survey and captured the species observed, it is possible that this type of survey may have missed plants here and there that were not visible or obstructed by habitat.

Project Area

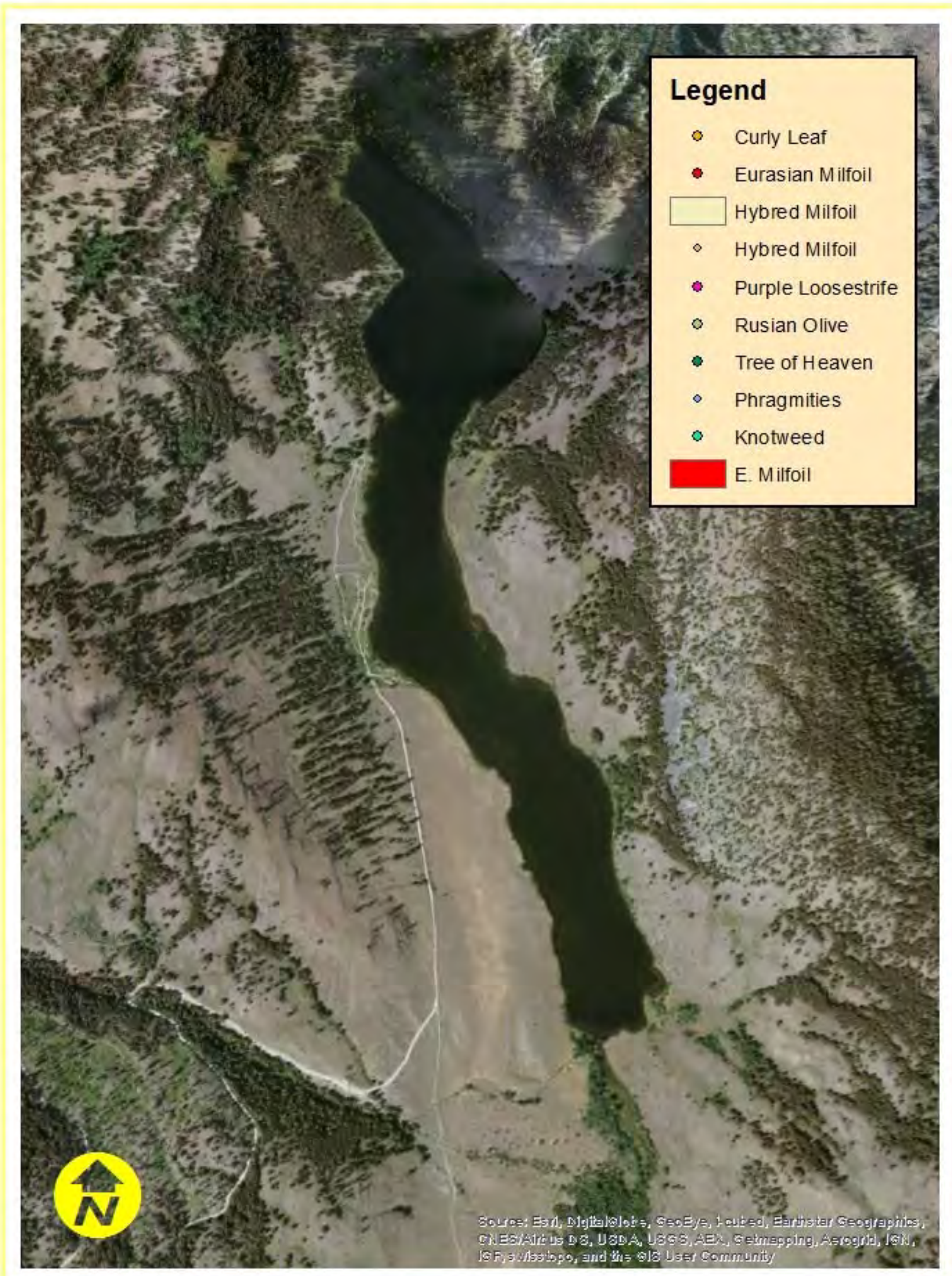
A lake by lake discussion of the team findings is presented below.

Sidley Lake

Sidley Lake

Sidley Lake is a relatively shallow lake system compared to many of those surveyed. There was a vary sparce submerged aquatic plant community present in this system. The shoreline was also relatively bare and free of emergent aquatic plant growth. There was a rapid transition from water to upland. The team did observe and map a few Purple Loosestrife plants as noted on the map.

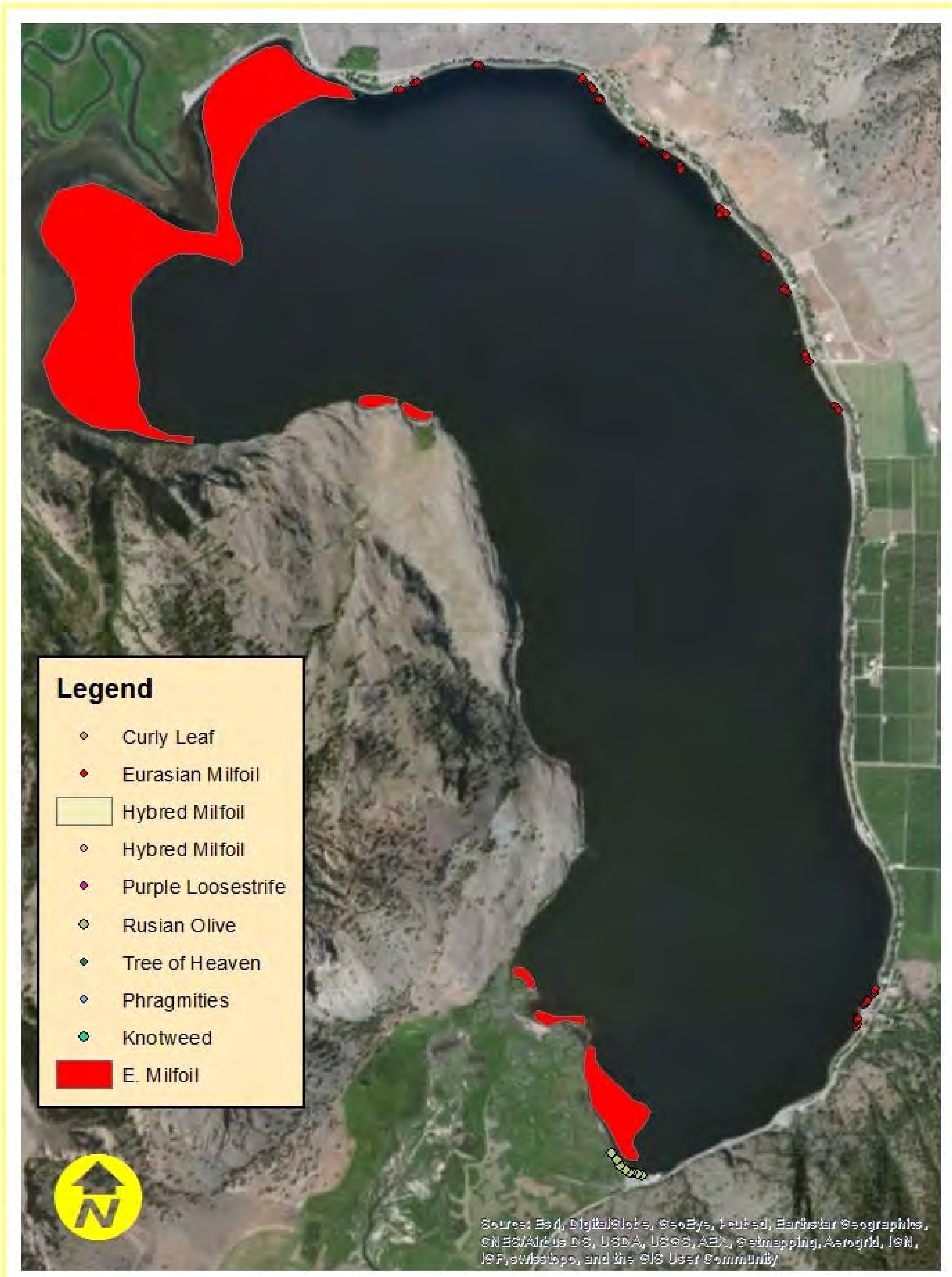
Chopaka Lake



Chopaka Lake

Chopaka Lake is a relatively isolated lake in the mountains above Palmer Lake. The access is primitive. The lake supports a native aquatic plant community dominated by *Chara sp*., Elodea and Pondweed species in the narrow littoral area. There were some native milfoil species observed as well. No noxious aquatic weeds were observed by the visual survey. The shoreline transitions rapidly to upland and there is very little wetland habitat present.

Palmer Lake



Palmer Lake

Palmer Lake exhibited large stands of dense Eurasian watermilfoil as located by the polygons shown on the map. There were also a number of locations where individual Eurasian watermilfoil plants were noted along the north and eastern shorelines. The majority of the western shoreline is rock and the littoral areas are non existant, there is no or very limited habitat present.

The primary infestation is in the northwestern bays of the lake. This shallow zone is densly colonized in areas outside the recent treatments performed a few years back in this area. The areas within the treatment zones are less dense with native aquatic plants mixed int, but the Eurasian watermilfoil plants are rapidly moving back into these areas.

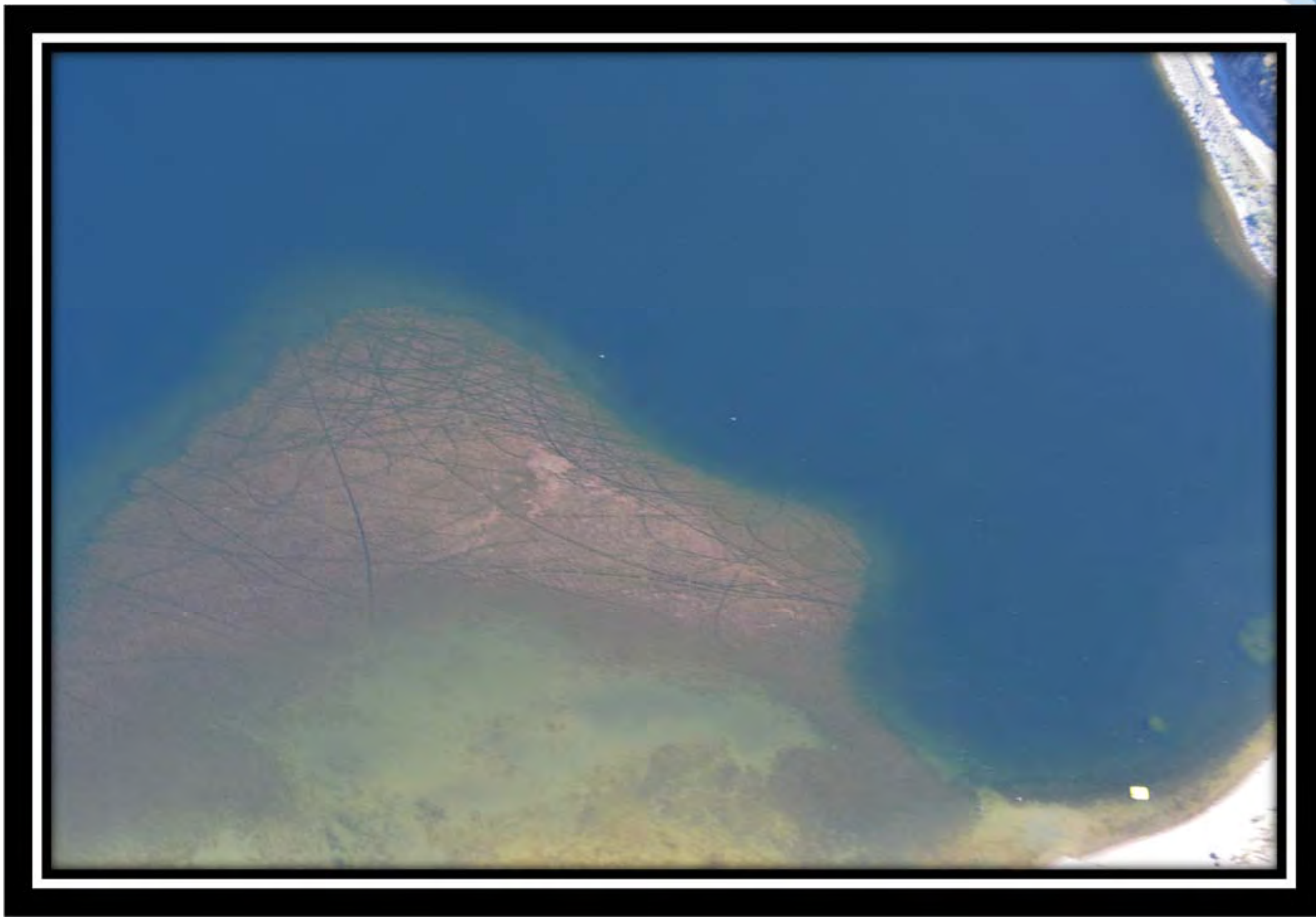
The polygon in the northwest bay totals 143.8 acres.

There are two polygons in small coves on the rock shoreline south of the major infestation and those Eurasian watermilfoil beds total 1.53 and 1.26 acres.

There are three Eurasian watermilfoil polygons at the southern end of the lake just to the west of the Bureau of Reclamaton Public Access site. These polygons are dense monocultures of EWM and total 13.65 acres, 1.72 acres and 0.99 acres respectively.

The scattered stands of Eurasian watermilfoil located as points around the lake shoreline can be expected to expand over time and will eventually form weed beds. At this point, they are stands of plants from one root crown generally.

There are some shoreline riparian areas on the south end of the lake. There were Russian Olive trees present as mapped. The remaining shoreline areas were rock or developed and transition rapidly to upland habitat. There is very little emergent vegetation present around this lake.



This is the 13 acre Eurasian watermilfoil infestation on the south end of Palmer Lake, the weed bed is a monoculture of this noxious weed species and grows to the 20 foot contour in this area.

Whitestone Lake

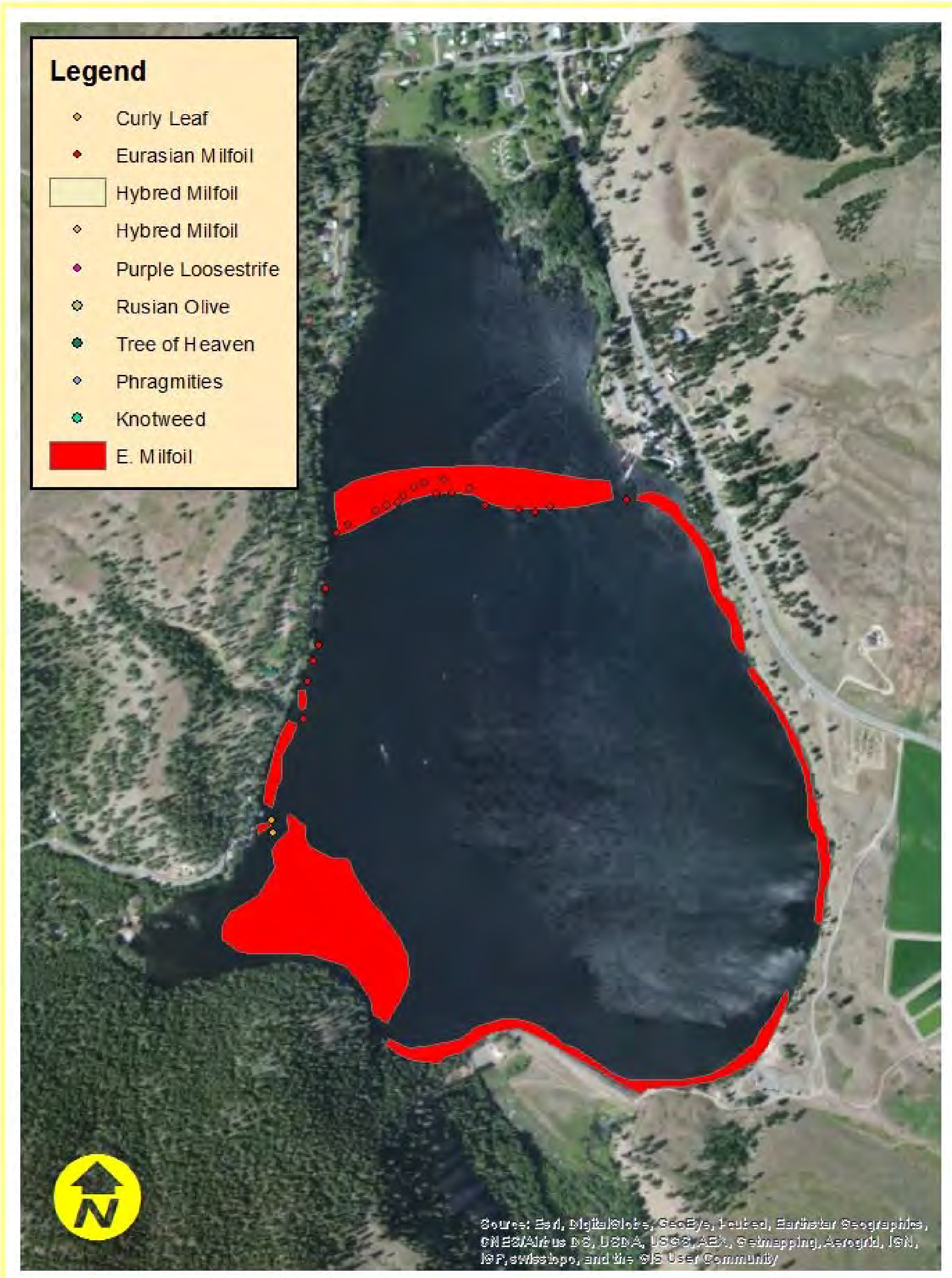
Whitestone Lake

Whitestone Lake is a shallow system carpeted by dense monocultures of *Chara sp*. (a macro algae that thrives in hard water lake systems). There were however some very defined areas where Eurasian watermilfoil had established in this system as mapped. There were a few scattered plants off of the public boat launch. There was one smaller patch on the southwestern shoreline as mapped totaling 0.39 acres. There is a second location just north of the boat ramp on the eastern shoreline that totals

1.45 acres in size. The remainder of the littoral area are totally covered with Chara. The Chara probably is taking up space and to some degree limiting expansion of the Eurasian watermilfoil present.

The shorelines of the lake have well established communities of Russian Olive present as mapped. The team also noted some locations where Tree of Heaven were present, one in the southeast corner of the lake and the balance along the roadside close to the lake north of the public access.

Conconully Lake

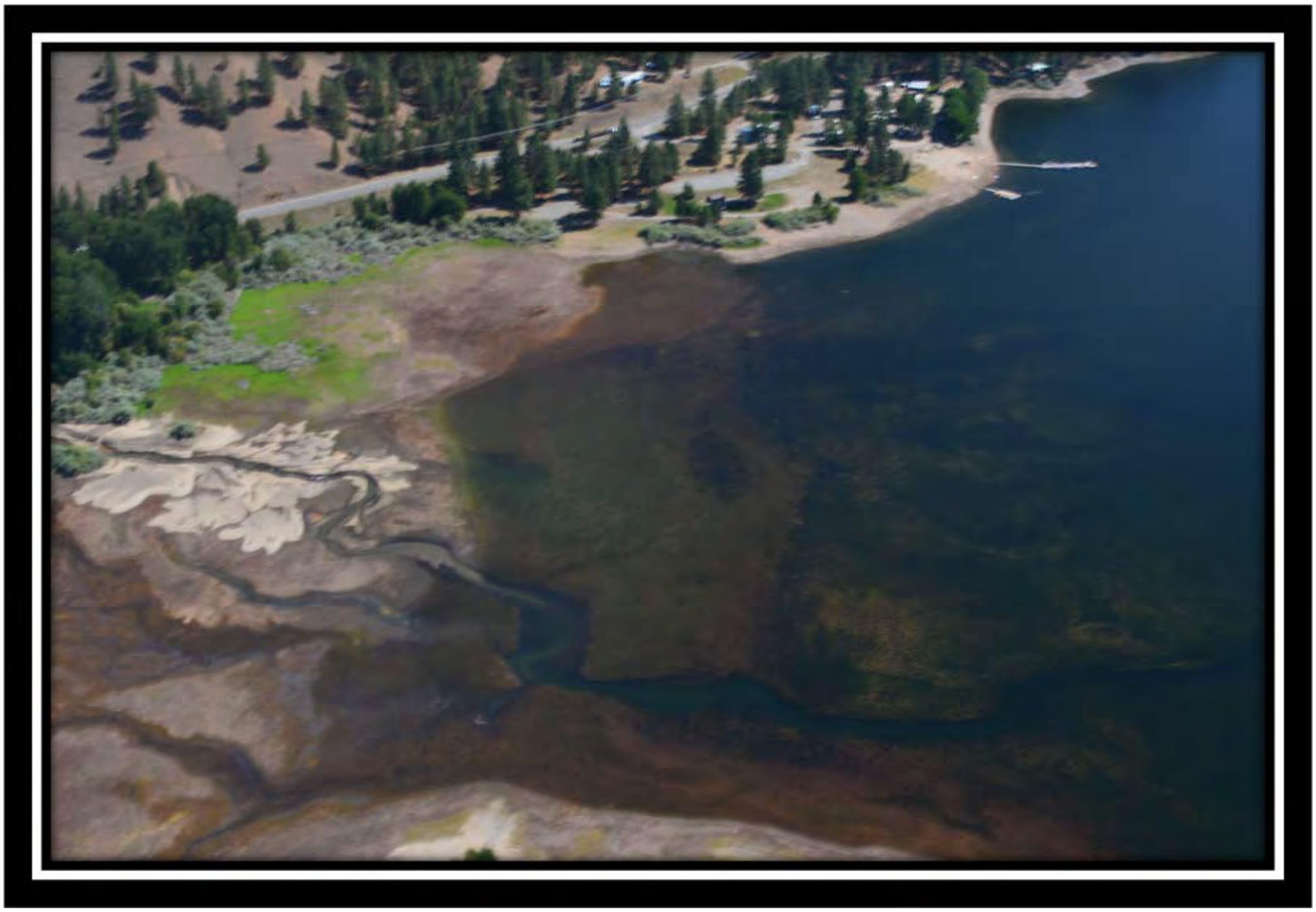


Conconully Lake

This lake system was heavily impacted by Eurasian watermilfoil throughout the current littoral area. It should be noted that the lake level at the time of survey was extremely low. The mapped 20 foot depth contour was the approximate location of shoreline at the time of survey. In higher water years, the milfoil present as mapped here may be in water depths where light and pressure could limit growth, and the areas of exposed lake bottom in the northern portion of the basin could be colonized. About 50 percent of the EWM mapped this year would normally be below the 20 foot depth contour.

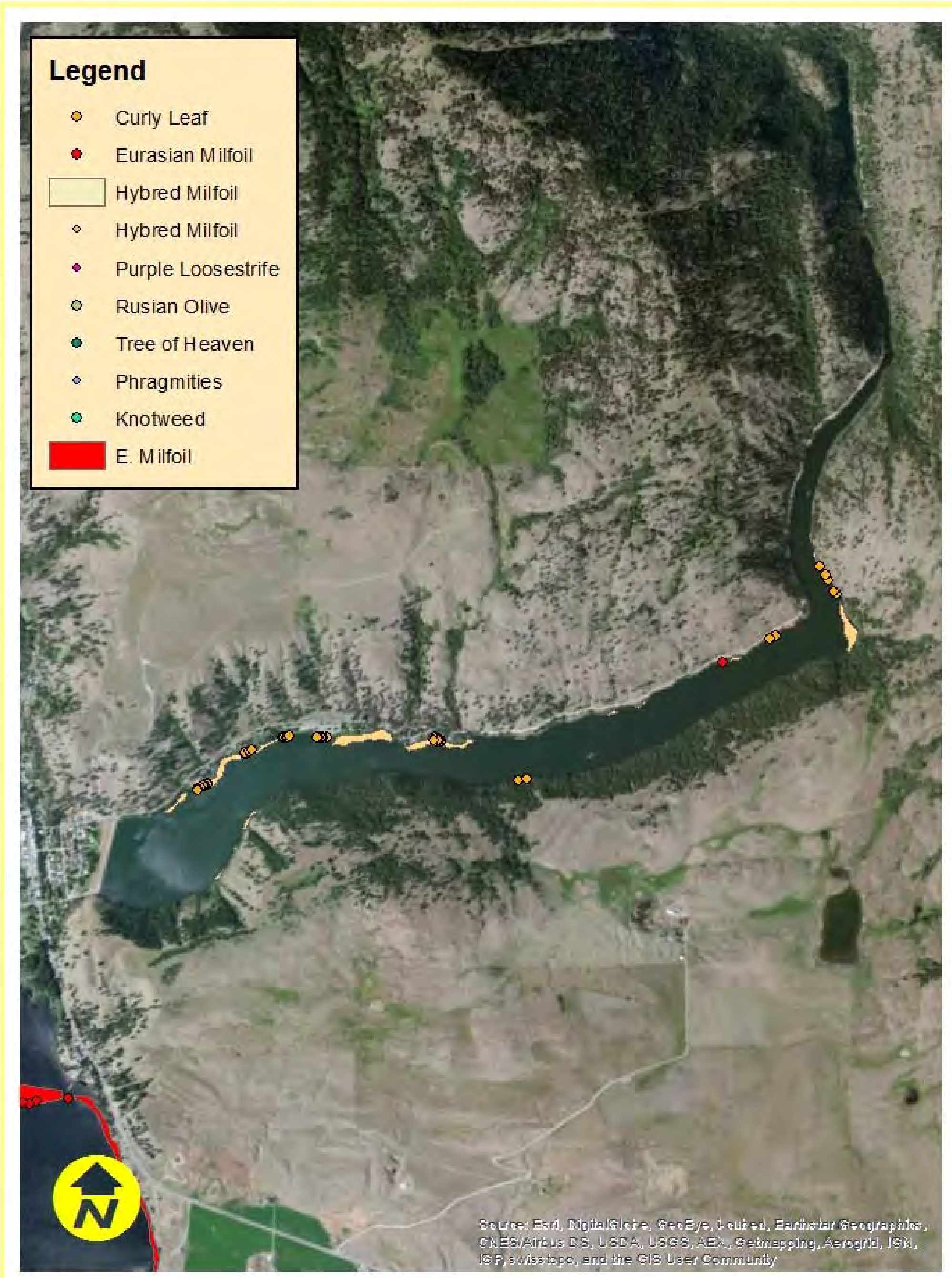
The EWM polygons from the northern one clockwise around the lake are 10.72 acres, 2.51 acres, 2.43 acres, 5.23 acres, 18.71 acres, 0.10 acres, 1.10 acres, and 0.14 acres. There are some additional scattered EWM plants as mapped and two locations where Curly Leaf Pondweed were observed.

The extreme variation in water depth and exposed littoral area have eliminated wetland areas on the lake shoreline.



Approximate location of 20 foot contour during full pool of this lake. Dense Eurasian watermilfoil beds are present in deeper water at this time. This may be mitigated by light and pressure during higher water years. If this lake goes up and down like this on a seasonal basis, these deeper water beds have a higher probability of surviving.

Conconully Reservoir

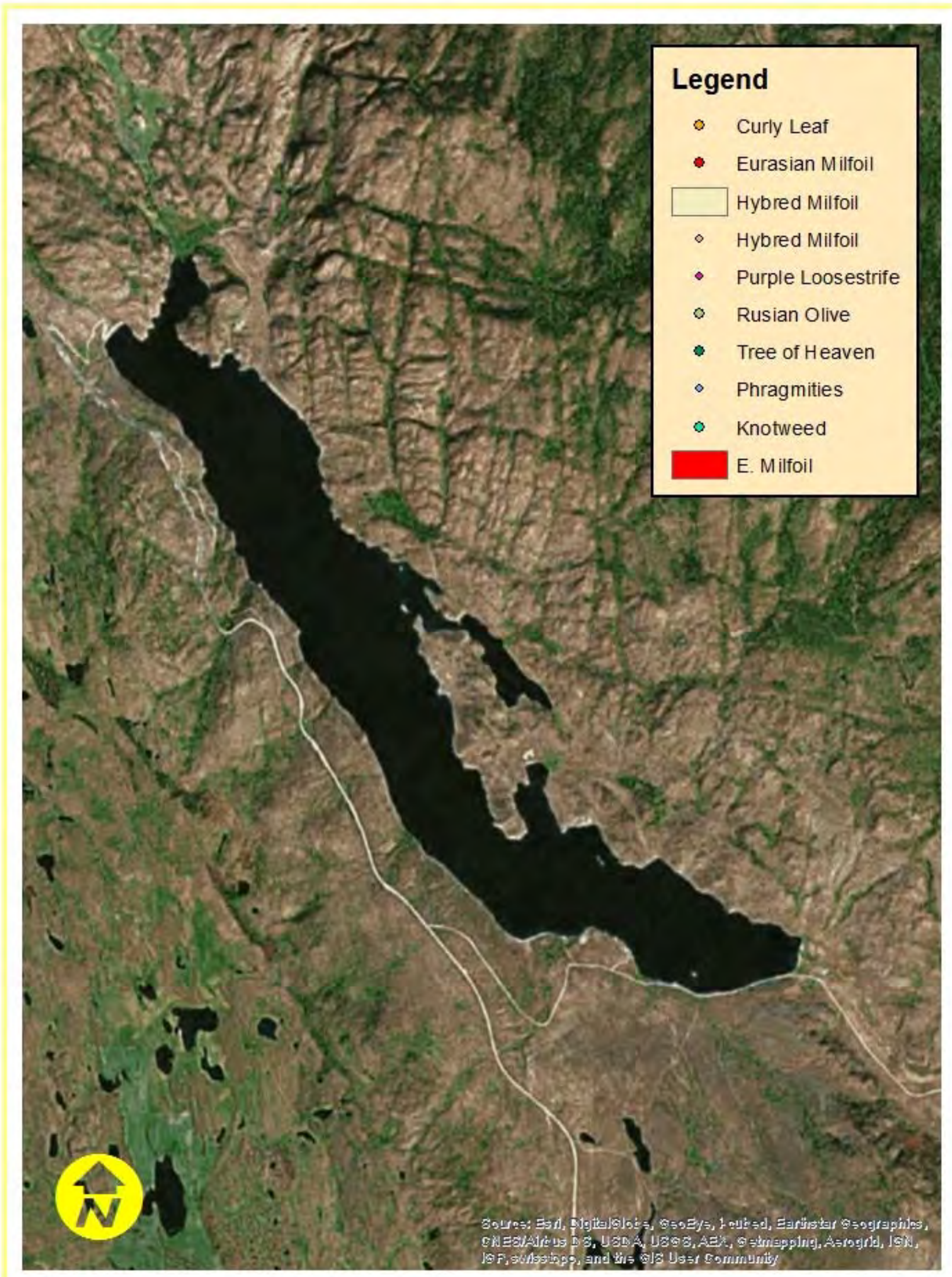


Conconully Reservoir

This lake system was heavily impacted by Curly Leaf Pondweed in the littoral areas that exist. This lake drops off rapidly and the majority of the shoreline is hard rock. As such, the habitat available to support aquatic weed growth is largely limited to a narrow band along the shoreline, there are better conditions for aquatic plant growth along the northern developed shoreline and at the east end before the northern arm of the reservoir. Dense Curly Leaf Pondweed beds were present as mapped and additional locations where individual plants were located as mapped. The acres of infested lake bottom starting at the northern edge of the dam and moving clockwise around the lake are 0.63 acres, 1.47 acres, 0.57 acres, 2.71 acres, 0.93 acres, 0.66 acres, 0.07 acres, 0.15 acres, 0.11 acres, 0.15 acres, 2.07 acres. 0.31 acres, 0.06 acres, and 0.16 acres. There were scattered locations where CLP was mapped as a single plant as noted as well. There was one point where individual Eurasian watermilfoil plants were discovered and mapped.

There were no areas where noxious emergent plants were observed. This reservoir has a very steep and rocky shoreline throughout and this limits the establishment and growth of these species. The lake transitions to upland immediately at the waters edge.

Omak Lake

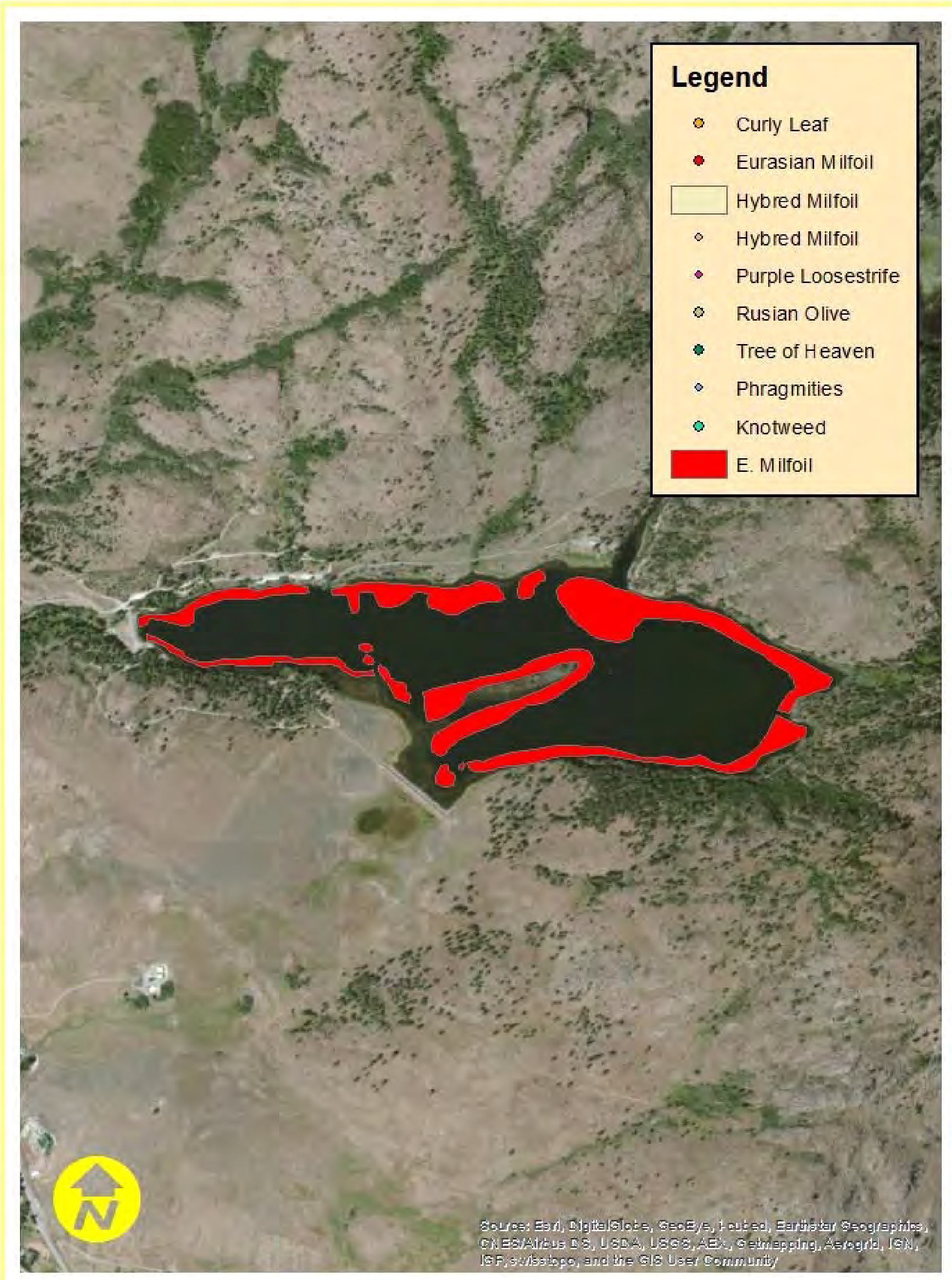


Omak Lake

Omak Lake is one of the larger lakes surveyed. This lake system is practically devoid of aquatic plant life. The lake bathymetry is such that littoral areas are minimized as transition to deep water is rapid. The lake shoreline and near shore shallows are basically rock formations and provide little habitat for submerged or emergent vegetation. Where vegetation was present it was native pondweeds and elodea species.

Representative shoreline and littoral area of Omak Lake. Water is clear, drop off to pelagic waters is rapid and desert conditions exist at the shoreline margins. Wetland habitat is virtually non-existent on this lake.

Leader Lake



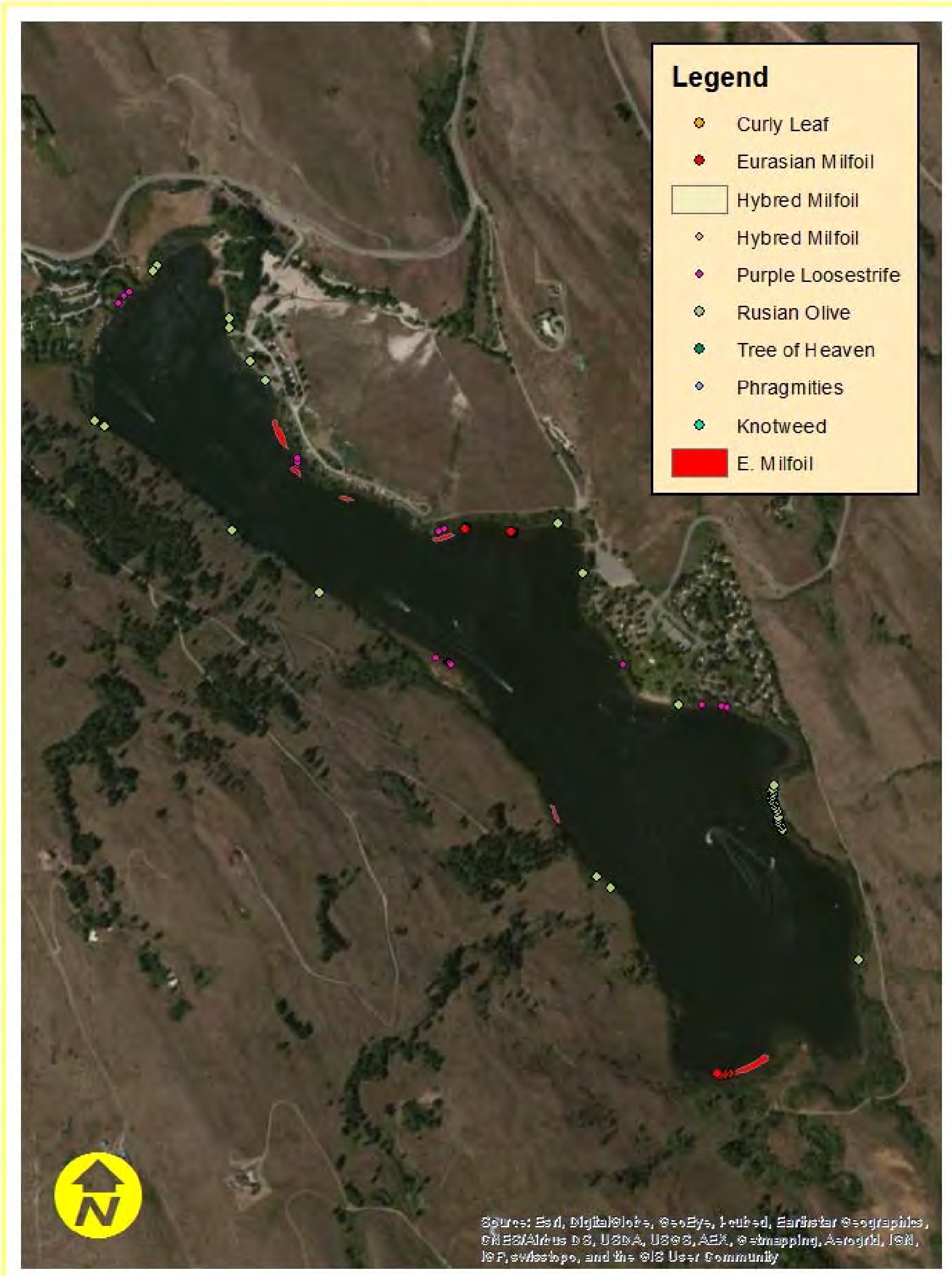
Leader Lake

Leader Lake is a shallow system and exhibited an algae bloom at the time of survey. This lake is heavily infested with Eurasian watermilfoil. Some areas of the lake has dense filamentous algae mats on the surface of the aquatic weed beds. The area of the EWM polygons mapped are from dam and access point clockwise around the lake 2.66 acres, 4.97 acres, 0.73 acres, 12.21 acres, 6.10 acres, 0.05 acres, 0.48 acres, 8.36 acres, 0.63 acres, 0.11 acres, 0.14 acres and 2.12 acres.

There was little to no wetland habitat present on this lake, the water levels were down approximately five feet. The algae bloom obscured visibility into the deeper areas of the lake. Rake tosses in these areas did not locate additional noxious aquatic weed species.

Note the planktonic and filamentous algae blooms present on this lake. This can limit observation, rake tosses in deeper water did not locate additional noxious aquatic weed growth.

Pearygin Lake



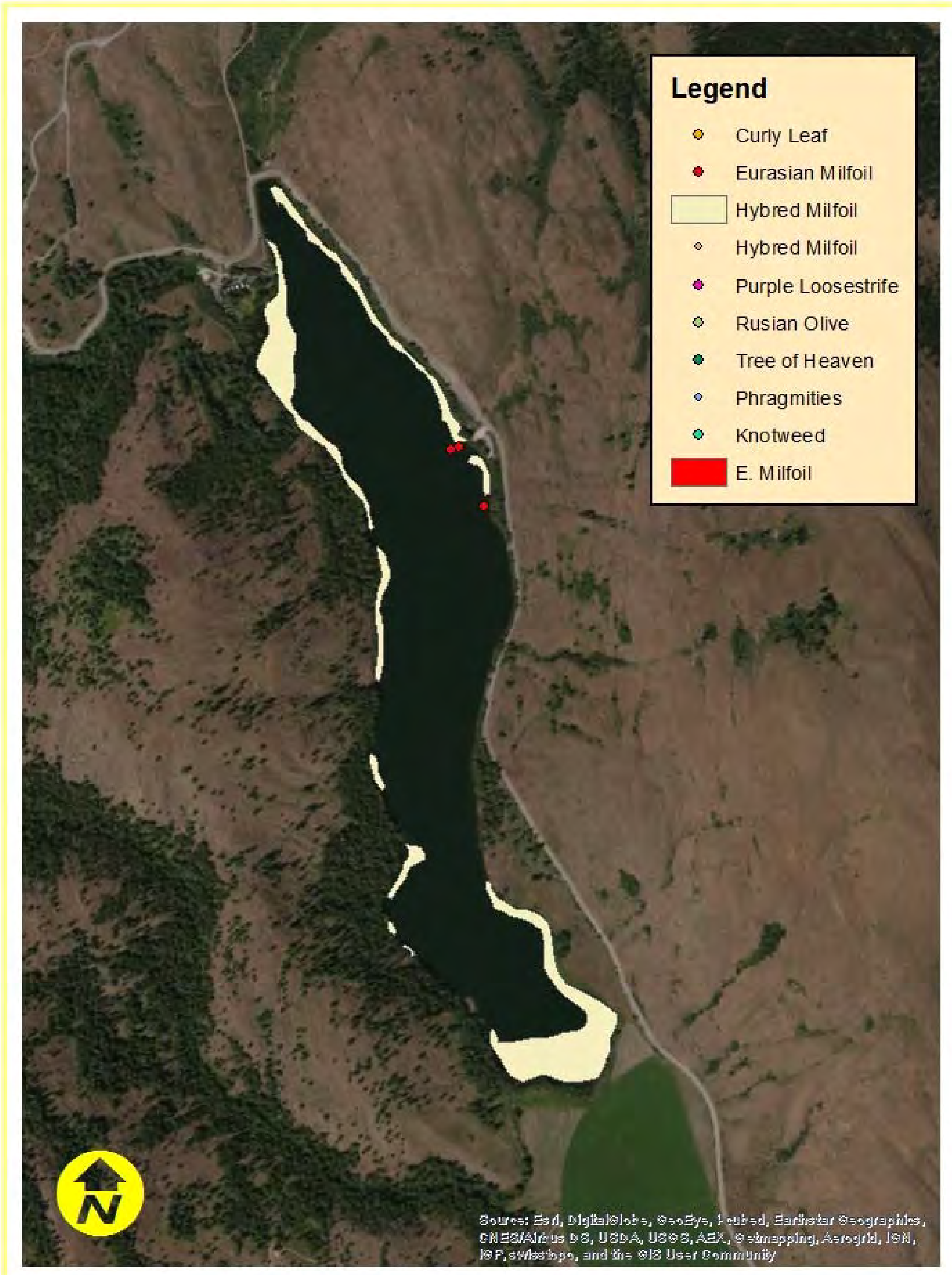
Pearrygin Lake

This lake near Winthrop has bathymetry that drops off fairly rapidly limiting the littoral areas of the lake to the near shore areas. There were scattered colonies of Eurasian watermilfoil present in the lake, but much of the littoral area was free from this noxious weed at the time of this survey. Moving counter clockwise from the boat launch at the state park (the Fish and Game access was closed for construction at the time of this survey) the EWM beds are 0.08 acres, 0.043 acres, 0.03 acres, 0.17 acres, 0.04 acres and 0.23 acres. There are also scattered plants as mapped. This lake has more of an established wetland belt around the shoreline than any of the mainly desert type lakes discussed to this point. We did note and map the location of observed Purple Loosestrife plants and Russian Olive present around the margins of the lake. The southern shoreline was rocky with a steep drop off and scattered PL plants were noted there. The northern shore had some more established cattail communities with PL mixed into those communities. There may be additional plants present that were not immediately visible during this type of survey.

It should also be noted that the aerial imagery showed evidence of a potentially toxic cyanobacteria bloom present at the end of August in this lake.

Note the bluegreen algae wind rowed at the southern end of the lake. This is evidence of microcystis, a species of blue green algae present in the lake. This algae can produce acute and chronic toxins that are a human health threat when present. The Washington Department of Ecology has a program available that includes laboratory analysis for toxin presence.

Patterson Lake

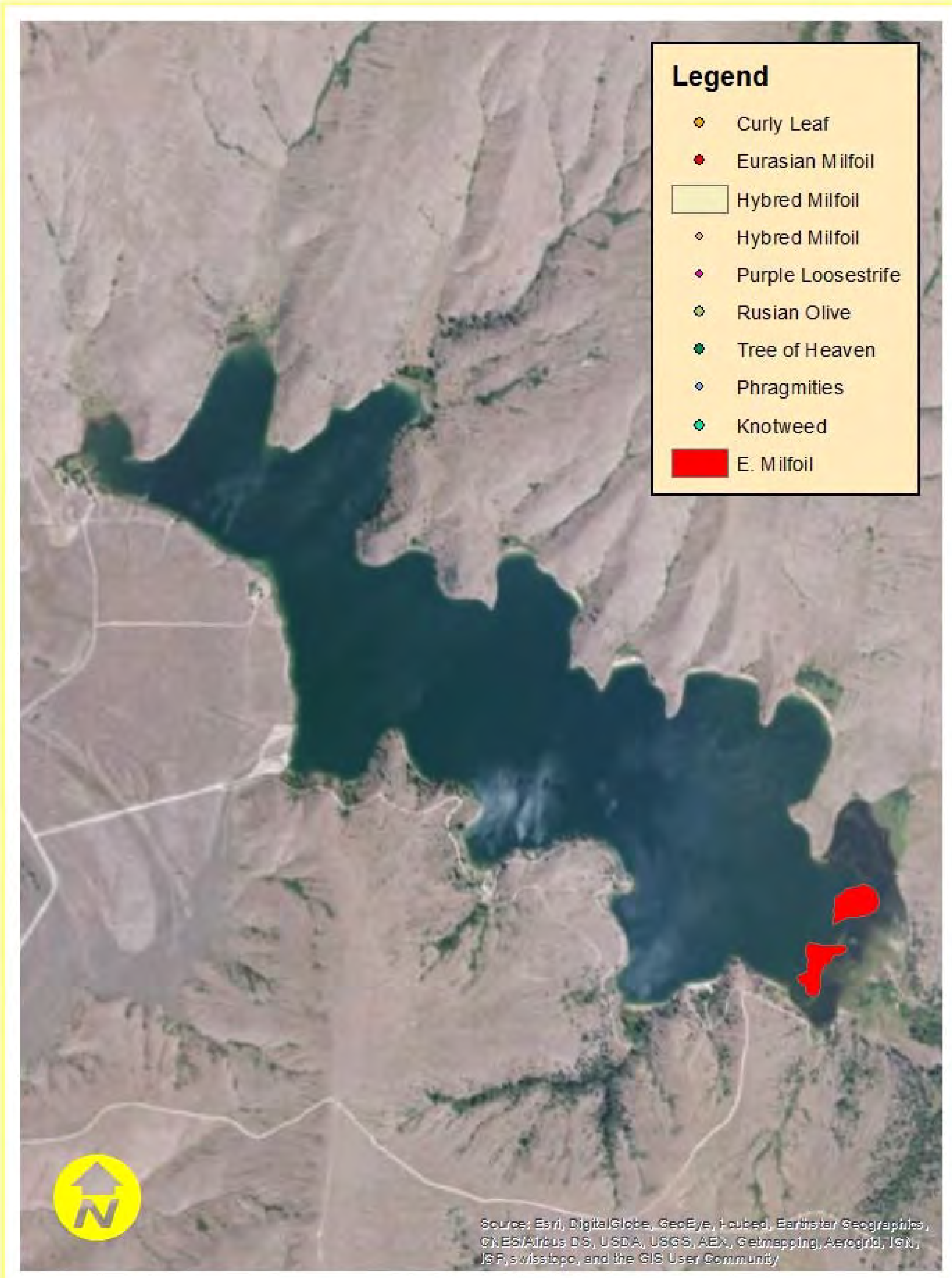


Patterson Lake

Patterson Lake is located near Winthrop and the bathymetry is such that the littoral areas are narrow, the lake drops off to deep water rapidly. There were three locations where Eurasian watermilfoil plants were observed at the public boat ramp as mapped. The majority of the remaining vegetation in the lake was a monoculture of milfoil plants that had characteristic of EWM and native species and were not clearly Eurasian. We mapped these as suspected hybrid milfoil or close relatives to EWM. The polygon acreage clockwise from the public boat ramp are 0.44 acres, 10.78 acres, 0.05 acres, 0.10 acres, 0.81 acres, 0.36 acres, 1.29 acres, 6.13 acres and 3.25 acres.

No emergent noxious aquatic weeds were observed during the visual survey of this lake.

Buffalo Lake



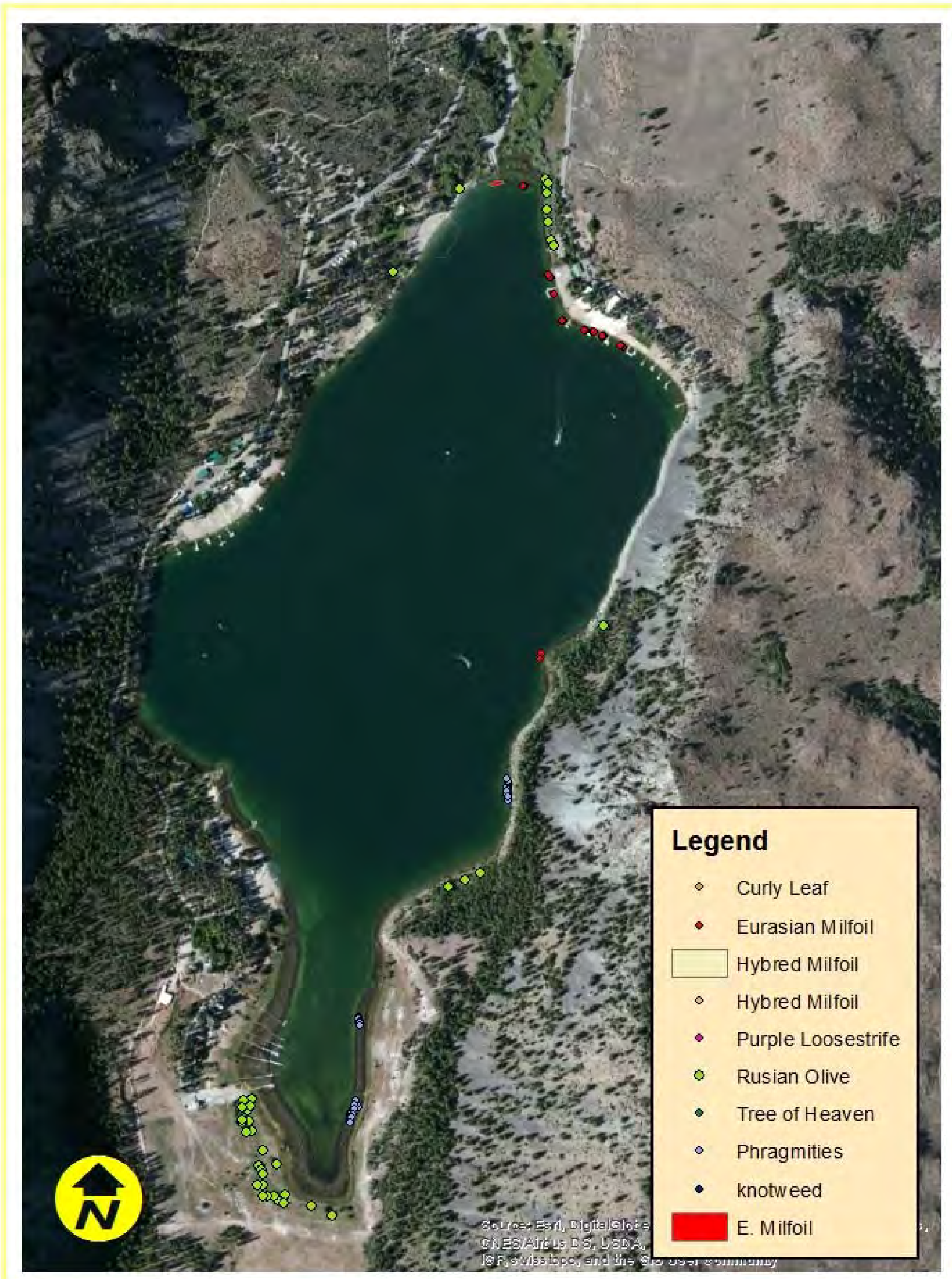
Buffalo Lake

Buffalo Lake was another largely desert environment lake system with a very narrow littoral area and rapid transition at the shoreline from lake to desert. The lake level was down about 5 feet from high water and the vast majority of the littoral shoreline had no aquatic plant growth present. The exception was the eastern shoreline where there were shallow margins of the lake that supported aquatic plant growth. There were two Eurasian watermilfoil beds present at this location that were 3.8 acres and 3.57 acres respectively. There were also dense filamentous algae mats present over other nearby vegetation, digging through these mats at some locations found mostly Chara present, but there may be some additional EWM plants here that are obscured from visual survey detection.

The team did not observe wetland invasive species, the margins of this lake transitioned rapidly to desert.

Dense filamentous algae mats covered much of the littoral vegetation in this portion of Buffalo Lake, there may be additional EWM present under these mats that are obscured. Our team did investigate a number of locations within these mats and found Chara and Elodea present.

Alta Lake

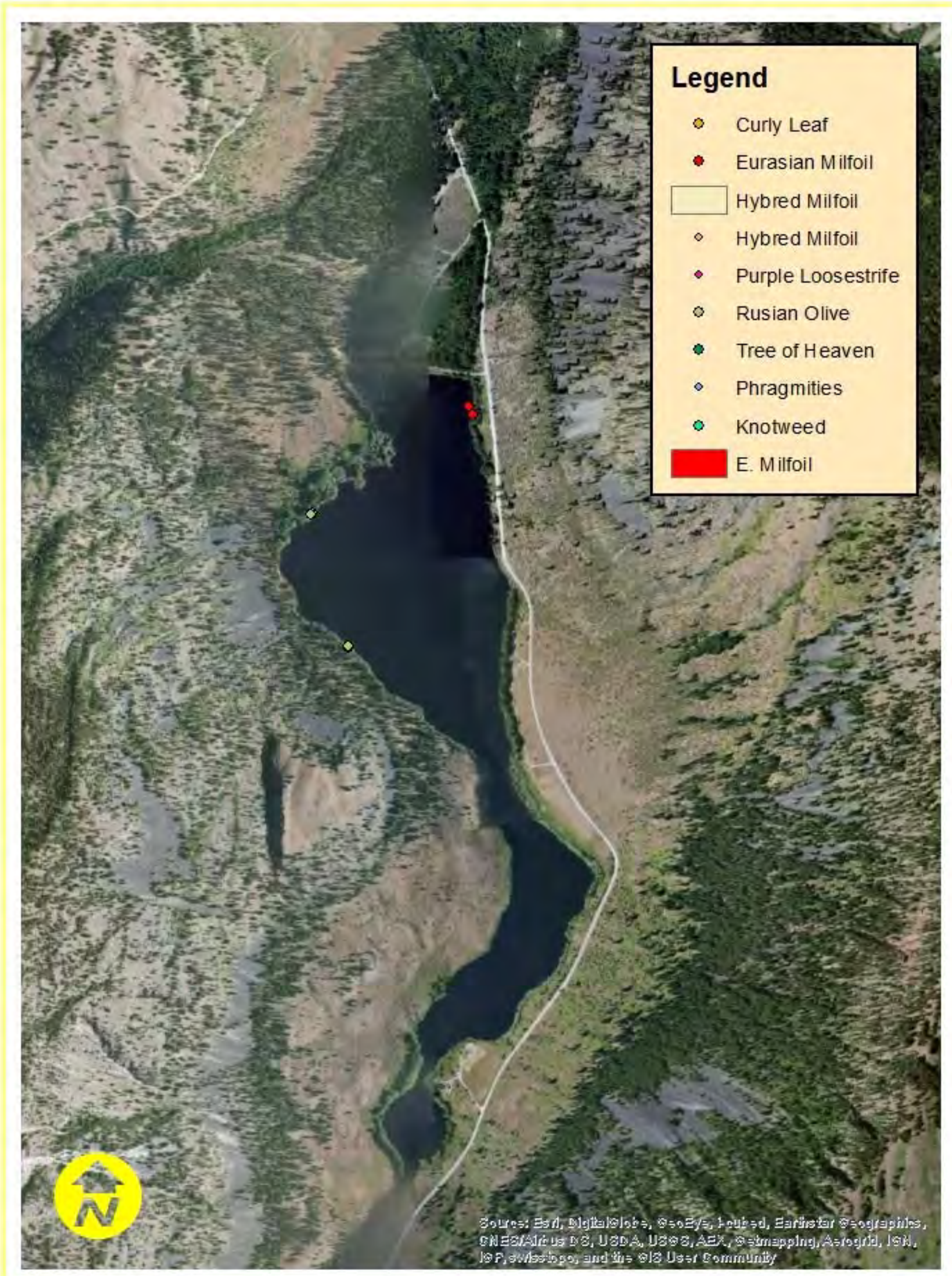


Alta Lake

Alta Lake with the exception of the southern cove, has a narrow littoral area and drops off rapidly to deep water. There was little submerged aquatic plant growth present in this lake, but pioneering colonies of Eurasian watermilfoil and Curly Leaf Pondweed were observed. The State Park public boat launch was closed at the time of survey and smaller hand carried johnboat was used to access the lake. There was one small patch of Curly Leaf pondweed noted just off the dock at the public ramp. There was a larger patch of Eurasian watermilfoil just off shore from that totaling 0.03 acres in size and there were scattered individual EWM plants along the shoreline as mapped.

There were a number of locations with established Russian Olive trees present at noted. There were also two locations on the southwestern shoreline that exhibited Phragmites as mapped.

Blue Lake



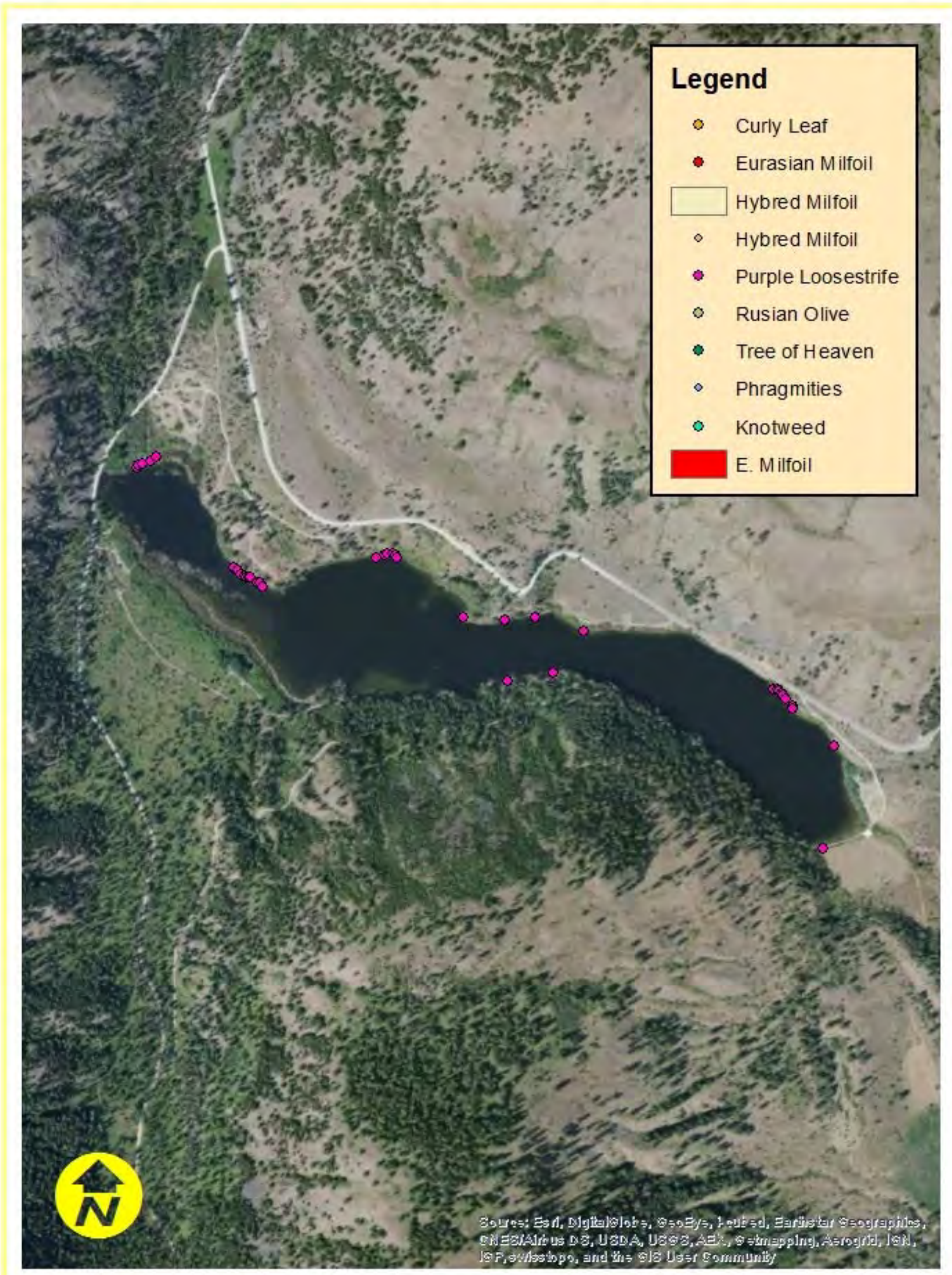
Blue Lake

Blue Lake has three distinct basins that drop off rapidly limiting habitat for aquatic plants to narrow shoreline bands. This lake has limited access and a hand carried johnboat was required to get onto the water. The small southern basin was largely devoid of aquatic plants except *Chara sp*. The middle basin had narrow bands of native submerged vegetation with extensive filamentous algae mats present on the top. The northern portion of that basin exhibited significant aquatic plant growth. The survey team found two locations in close proximity where Eurasian watermilfoil plants were located as mapped. This should be a candidate for early action.

There were some Russian Olive trees established along the bank as noted as well.

The southern basin of the lake with exposed lake bed and no vegetation dropping to the deep water hole.

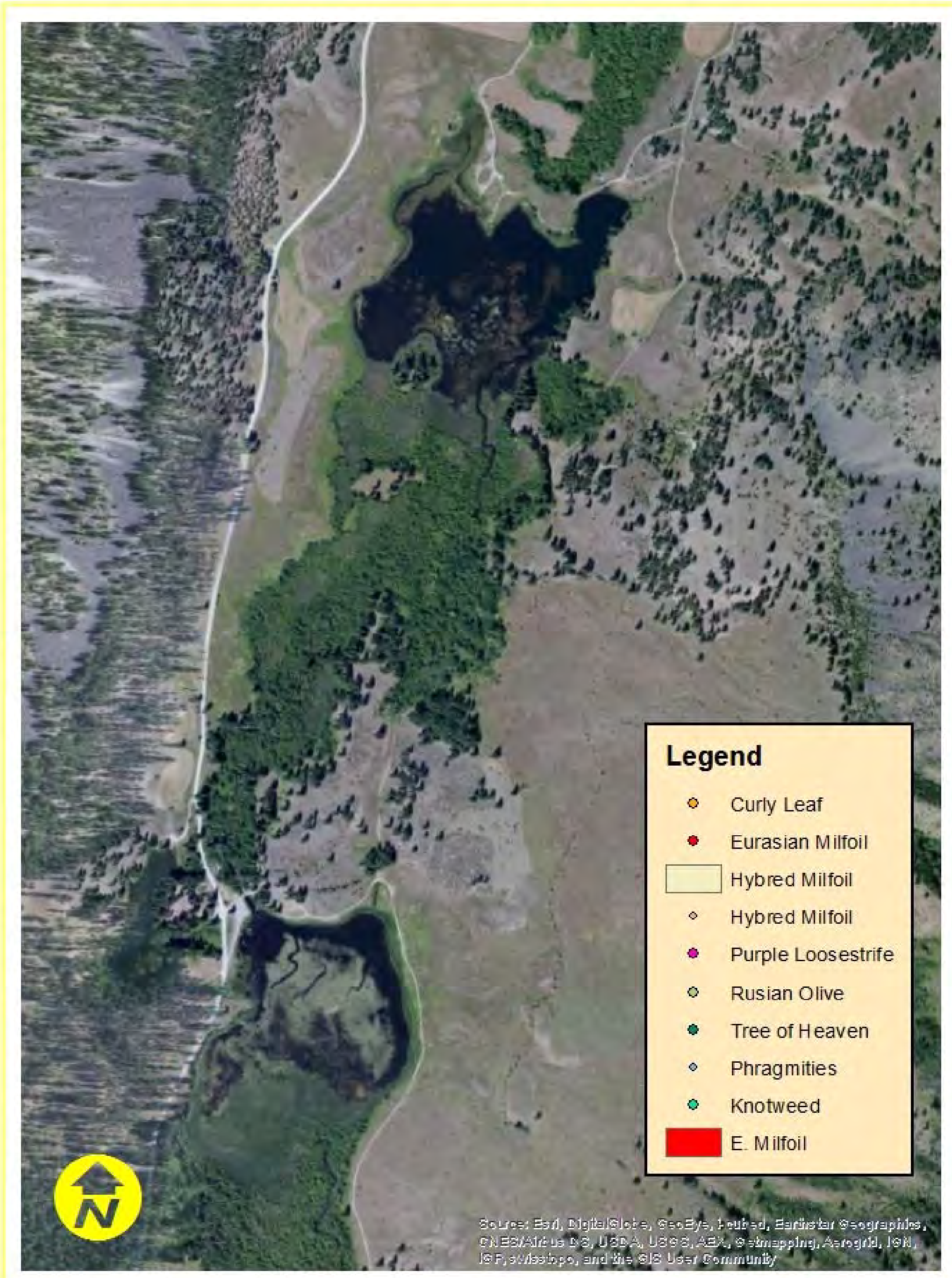
Fish Lake



Fish Lake

Fish Lake was relatively void of submerged aquatic plant growth. The public access was very limiting and a hand carried johnboat was required to access this site. There were a number of locations where Purple Loosestrife plants were observed around the margins of the lake as mapped.

Connors and Forde Lakes



Forde and Conner Lake

These two lakes were covered completely with dense filamentous algae mats at the time of this survey. This obscured the majority of the vegetation and was extremely difficult to move through with the type of boat that the ramp accommodated. We did perform a number of rake collections across the surface of the lake and through these algae mats and did not collect anything on the noxious weed list. So the visual survey did not note the presences of any of the listed species. A second look in the spring prior to formation of the algae mats would be recommended to get a clearer picture of these small water bodies.

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Okanogan County Survey of the Columbia River for Aquatic Noxious Weeds

FINAL REPORT

Beginning August 18th and ending August 29th, 2014, Lakeland Restoration Services, LLC (LRS) performed a survey from the Canadian Border of the Columbia River down to what is known as the Pateros Pool, and north on the Okanogan River to McLaughlin Falls. The purpose of this report is to define the methodology used and results for the survey.

Near the Canadian Boarder

Survey Methodology

LRS provided labor, materials and equipment necessary to complete the surveys on the Columbia River. On August 18, 204 Lakeland Restoration Services, LLC (LRS) started a survey on the Columbia River and Okanogan River for the Okanogan County Noxious Weed Control Board.

The goals and objectives of this survey were as follows:

- Survey entire Okanagan and Columbia River to Pateros pool for Aquatic and Riparian nuisance plants listed on the Washington invasive plant list.
- Identify new invasive plants introduced (Pampas grass)
- To identify populations of invasive aquatic and emergent plants.
- To identify populations of other invasive aquatic species.
- Determine future accessibility and control measures to treat populations.
- Estimate treatment costs associated w/ treatment program.
- Map the infestations and provide PDF and SHP data to Okanagan county

Species of first concern included the species below, many of which are not known to occur in Okanogan County.

- Flowering rush – Butomus umbellatus
- Hydrilla – Hydrilla verticillata
- Variable leaf milfoil – Myriophyllum heterophyllum
- Floating primrose-willow – Ludwigia peploides
- Brazilian elodea – Egeria densa
- Eurasian watermilfoil – Myriophyllum spicatum
- Parrotfeather – Myriophyllum aquaticum
- Water primrose – Ludwigia hexapetala
- Yellow archangel – Lamiastrum galeobdolon
- Yellow floating heart – Nymphoides peltata
- Curly-leaf pondweed – Potamogeton crispus
- Fragrant water lily – Nymphaea odorata

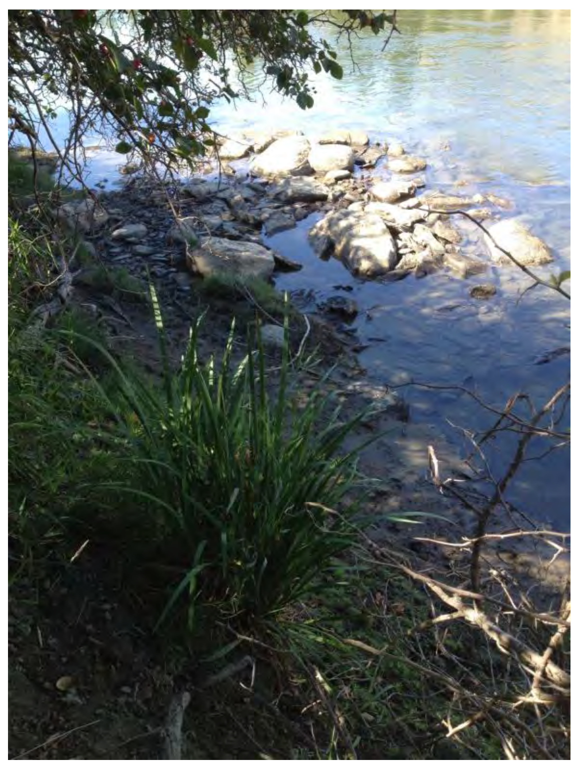
Curley Leaf Pond Weed
in the Okanogan

The second concerns was recording the species below.

- Yellow flag iris – Iris pseudacorus
- Butterfly bush – Buddleia davidii
- Common reed – Phragmites australis (non-native varieties)
- Knotweed species – Polygonum x bohemicum, schalinense, polystachum, cuspidatum
- Loosestrife species – Lysimachia vulgaris, Lythrum virgatum
- Saltcedar – Tamarisk ramosissima
- Russian olive – Elaeagnus angustifolia
- Common cordgrass – Spartina anglica
- Dense-flowered cordgrass – Spartina densiflora
- Saltmeadow cordgrass – Spartina patens
- Smooth cordgrass – Spartina alterniflora
- Poison hemlock – Conium maculatum
- Japanese eelgrass – Zostera japonica
- Non-native cattail species and hybrids
- Reed canarygrass – Phalaris arundinacea
- Tree of Heaven – Ailanthus altissima

Yellow Flag Iris on the Okanogan River

Yellow Flag Iris on the Columbia



To accomplish the above goals LRS conducts surveys in the following manner:

Littoral Survey

In order to identify EWM and other invasive plant populations, a survey of the entire littoral area is conducted. The littoral zone is defined as the shallow area near the shore of a body of water that extends from the shoreline lakeward to the limit of occupancy of rooted plants. This survey is conducted from a boat using rake throws, visually and or underwater viewers. The entire littoral zone will be surveyed by navigating in a regular pattern so that the entire bottom is observed. If surveying from a boat, regular rake throws are conducted to check for EWM in areas with limited visibility. As water clarity decreases, the frequency of rake sampling is increased, paying special attention to boat ramps. When EWM or other invasive aquatic species are found, the GPS location is recorded, the area of growth is outlined with the GPS, and the percent cover is estimated. Cover estimates are recorded as either dense, sparse or no EWM cover. When the bottom cannot be seen underwater viewers and rake throws are used to determine the percent of cover. Also noted with GPS coordinates is the location of invasive emergent shoreline plants as they are detected (purple loosestrife, phragmites, yellow iris, tamarisk, Russian olive, etc.).

Point Intercept Survey

The point intercept method is a relatively quick and effective way of quantifying the distribution and frequency of aquatic vegetation. Points are pre-selected and are placed in a regularly spaced grid or at random points on a GIS generated map of the water body. Sampling in this manner tracks changes over time in the aquatic plant community by repeatedly returning to the same points for sampling (Madsen 1999).

A point intercept survey of a body of water is typically conducted in two person teams. One person navigates the boat with a GPS to the proper point and a second person makes observations. Upon arrival at a sampling point, the depth is recorded and, if possible, the sediment type (mud, sand, rock or organic) is determined. The reader then observes an area of water over the side of the boat using the same side of the boat every time. Species observed from the surface within the area are recorded on a data sheet. Sample rakes are used in areas where the bottom cannot be clearly seen. Samples are taken with two rake throws in a crossing pattern within the 1m x 1m sampling area and all additional species are recorded (Parsons et al. 2001). The GPS coordinates are recorded for any EWM that is observed while traveling between sampling points.

A species is only recorded once at each sampling point even if it is observed multiple times on the surface and in rake throws. The data sheets are arranged with all suspected species listed across the top and sample coordinates listed in the left column. When a species is found, a one (1) is marked in the appropriate column for that species. A zero (0) is entered to indicate the absence of a species at that point. Spaces are available for listing new species as they are found. A column will be provided to list various physical stages of EWM in order to gage the effectiveness of treatments a scale of one through five is used to record the status of plants observed. Five indicates no live EWM present, four indicates only a small sprig of EWM (very little live EWM present), three indicates sparse EWM (plants appear stressed, sparse growth, no plants on the surface), two indicates EWM, but not on the water surface (some plants appear distressed but fairly healthy, no plants on the surface) and one indicates EWM on surface (plants appear fairly healthy with little or no apparent control effects, plants on water surface). In addition, a column is provided for a cover estimate. Cover is reported as either dense, sparse or no EWM cover. In small lakes pre- and post treatment point intercept surveys are conducted over the entire water body. The pre-treatment survey is conducted before treatments are applied, preferably within several weeks prior to treatment. The post-treatment survey is a revisit to the same points and should be conducted late in the year (late August or September) in order to assure the maximum treatment effect is observed. In small lakes the pre-treatment survey is conducted concurrently with the littoral survey.

Invasive plants noted:

During the survey, Yellow flag Iris (Iris pseudacorus L) and Tree of Heaven (Ailanthus Altissima) were noted. Both plants, if allowed to proliferate can have detrimental effects on the native plant community, reduce the quality of recreation on the water body, interfere with hydroelectric operation, and reduce property values. Some of the other plants noted in the survey include, Knot Weed speicies, Phragmities, Purple Loosestrife, Reed Canary Grass, Eurasian Water Milfoil, Pondweeds, and Water Primrose.

Yellow flag iris (Iris pseudacorusan) invasive iris introduced from Europe. It grows monoculturalistically along the riparian areas of the water body. The plant can reproduce by rhizome or seed. The plant consumes large volumes of water thereby, defeating the purpose of water storage in reservoirs. Rhizomes break off and can provide navigation hazards.

Yellow Flag near Roosevelt

Tree of Heaven (Ailanthus altissima) is an invasive tree introduced from Asia. Tree of Heaven was found during the survey. The tree grows by rhizomatous behavior, grows very tall and thick. The only way to remove this tree is to cut the tree and apply herbicides to the cut surface. Several applications may be required to achieve 100 percent
control. Simply cutting the tree encourages its spread. Several of the infestations are on private property that appears uninhabited. Landowner cooperation may be required to successfully control this plant.

Curly-leaf pondweed (Potamogeton crispuswas) was identified in the survey as an invasive plant. Most populations were found in shallow eddies throughout the survey.

American Pond Weed

Knotweed species (Polygonum x bohemicum, schalinense, polystachum, cuspidatum) In the Pacific Northwest, there are four similar species of invasive knotweed that are difficult to tell apart and share similar habitat, impacts and control methods. They are all large, robust perennials that spread by long creeping rhizomes to form dense thickets. Knotweed was found near Roosevelt on the Columbia River.

Phragmites near two rivers



Phragmites (australis) this tall wetland grass is also known as common reed. There are both native and non-native strains of this plant in Washington. Due to its aggressive tendencies and impact to waterways, the non-native strain or haplotype is a Phragmites found in both eastern and western Washington and some infestations are many acres in size. Most populations of phragmites in this survey area appears to be the native phragmites. One infestation close to the confluence of the Spokane River appears to be invasive.

Loosestrife species, (Lysimachia vulgaris, Lythrum virgatum) Purple loosestrife occurs in freshwater and brackish wetlands. It is a successful colonizer and potential invader of any wet, disturbed sites in North America. Associated species include cattails, rushes, sedges, and reeds. Purple loosestrife can sometimes grow in upland sites. Purple loosestrife is invasive and competitive and unavailing to native wildlife. It can quickly adapt to environmental changes and expand its range to replace native plants used for ground cover, food or nesting material.

Purple loosestrife was found throughout the survey areas on the Okanogan and Columbia River.

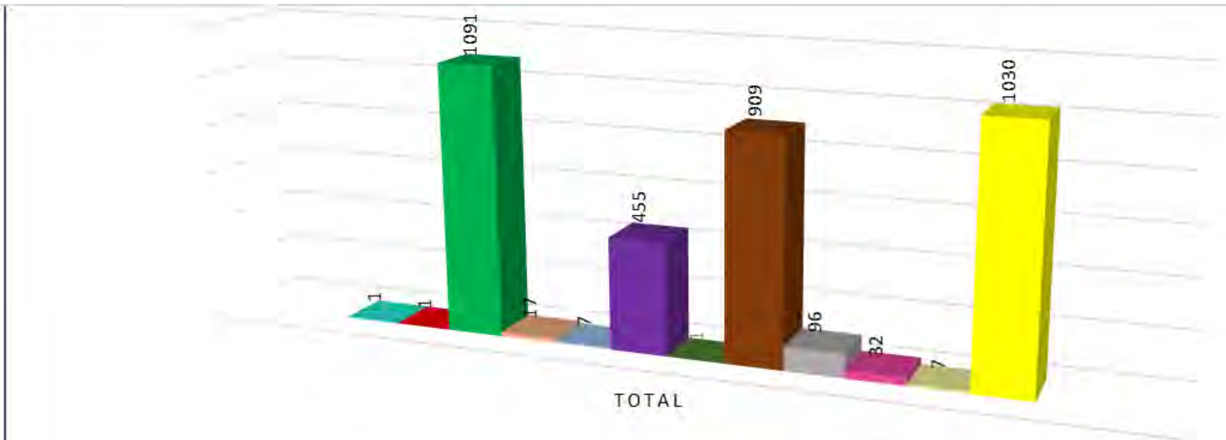
Reed Canary Grass on the Okanogan

This aggressive grass poses many challenges to management and creates significant problems for restoration projects. It spreads by rhizomes, fragments and seeds. The dense rhizomatous mats exclude other roots and make removal highly difficult. Stems fall and form mounds by the end of summer, further inhibiting native wetland species from re-colonizing infested areas

Rufus Woods Milfoil

Eurasian watermilfoil (Myriophyllum spicatum) was found throughout the survey in Pateros pool and in shallow eddies as well. Several hundred acres of infestation was mapped.

Survey Totals



	Total
Count of Common Reed	1
Count of Curly Leaf Pond Weed	1
Sum of EWM	1091
Sum of Fragrant Water Lily	17
Sum of Knotweed Species	7
Sum of Loosestrife Species	455
Sum of Pampas Grass	1
Sum of Reed Canary Grass	909
Sum of Tree of Heaven	96
Sum of Water Primrose	32
Sum of Yellow Floating Heart	7
Sum of Yellow Flag Iris	1030

Conclusion

Riparian and Aquatic invasive plants are having a profound negative impact of the river systems in Northeastern Washington. Large Yellow flag Iris populations were mapped in the Ponderay and Columbia Rivers from Long Lake to Pateros pool. Large populations of Yellow Flag Iris was identified up the Okanagan River to Omak.

Tree of Heaven was identified throughout survey area. Most infestations along river are escape vegetation from landscape plantings. However, once the trees reach the river, the plants fragment and re-infest the riparian areas. These plants should be controlled.

One planting of pampas grass was found above the river in Omak. The planting appears to be recent. Once seed heads are formed, plants will reproduce in river system.

Purple loosestrife was found in small populations. These plants typically found in and around YFI populations.

Reed Canary grass was also found in the Okanagan and Columbia River system. Populations correspond with YFI populations in most cases.

Eurasian water Milfoil and Curly Leaf Pondweeds were found in back eddies and quiescent waters throughout the survey areas in all river systems. Several hundred acres was identified in Brewster Pool. This infestation may best be controlled using harvesters, as the areas are shallow and flat. Removing nutrient loading will improve water quality.

Primrose was also located in 6 pts. In Pateros pool and up the Okanagan River to Omak.

Yellow floating Heart was found in 7 locations throughout the survey.

Flowering-Rush is an aquatic plant found along lakeshores and slow-moving rivers, and in water up to 9 feet deep. It resembles a true rush, flowering-rush is in its own family and can be distinguished by its attractive pink flowers. Flowering-rush competes with native wetland and shoreline vegetation and can crowd out more desirable species. No Flowering rush populations were identified in this survey, although ongoing surveys would be advised. There is infestation in the Ponderay River in Ponderay County.

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Parsons, J.K., K.S. Hamel, J.D. Madsen, K.D. Getsinger. 2001. The use of 2,4-D for selective control of an early infestation of Eurasian Watermilfoil in Loon Lake, Washington. J. Aquat. Plant Management. 39:117-125.

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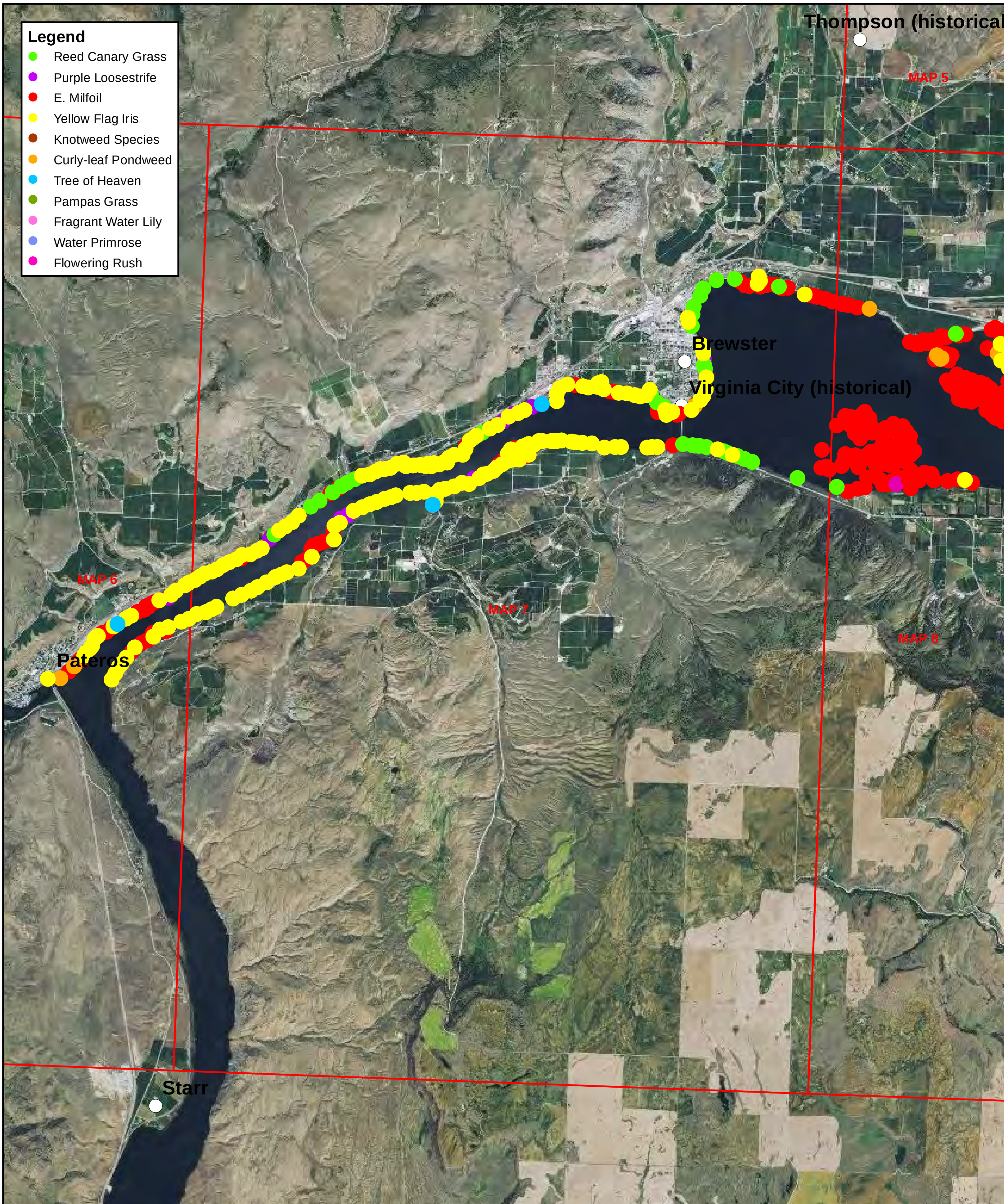
APPENDIX

MAPS

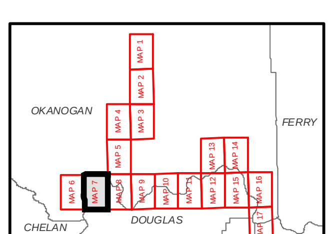


Okanogan County Weed Control Survey 2014

MAP 7

0 1 2 Miles

MAP EXTENT



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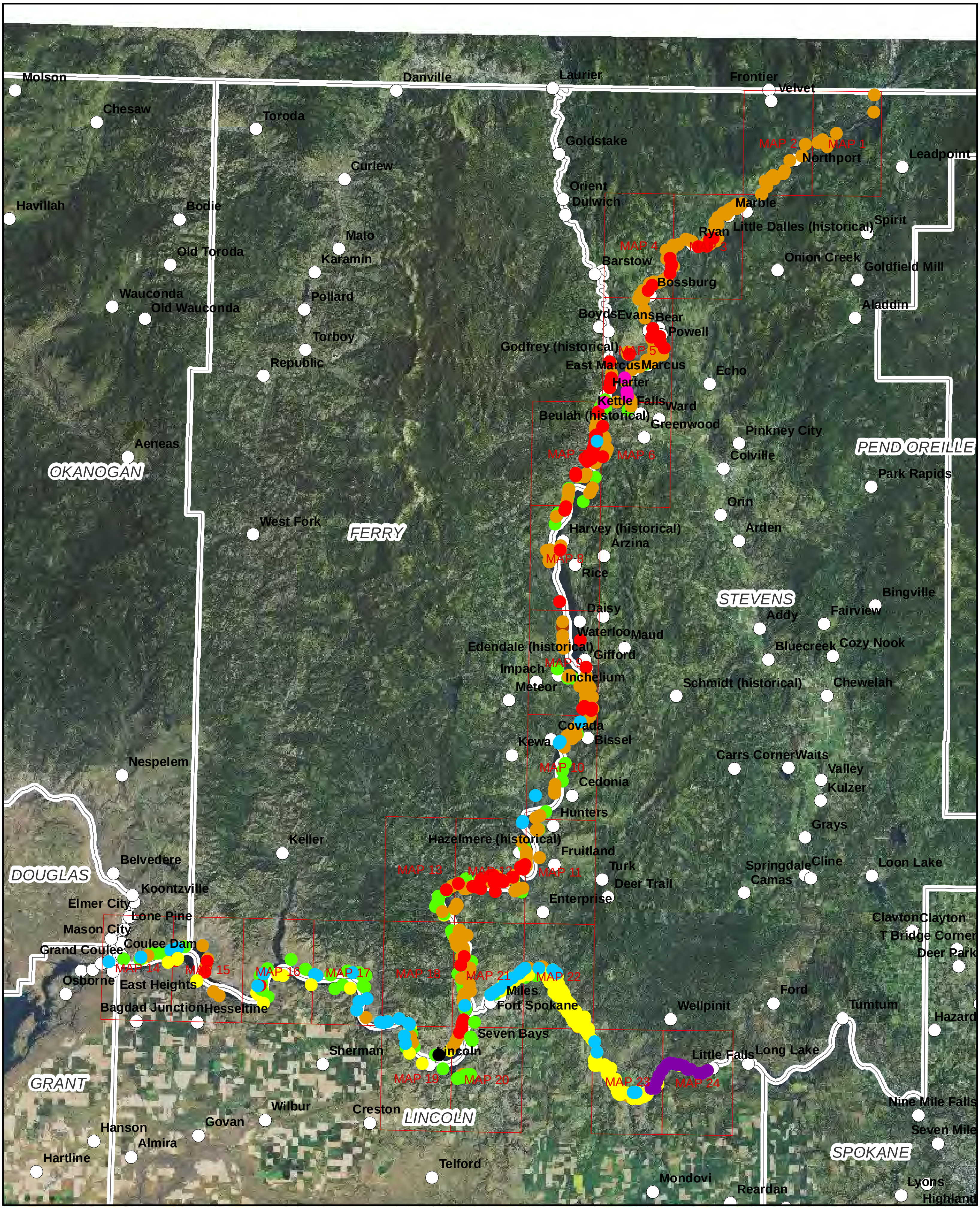

Columbia River and Spokane River Weed Control Survey 2014

0 5 10 Miles

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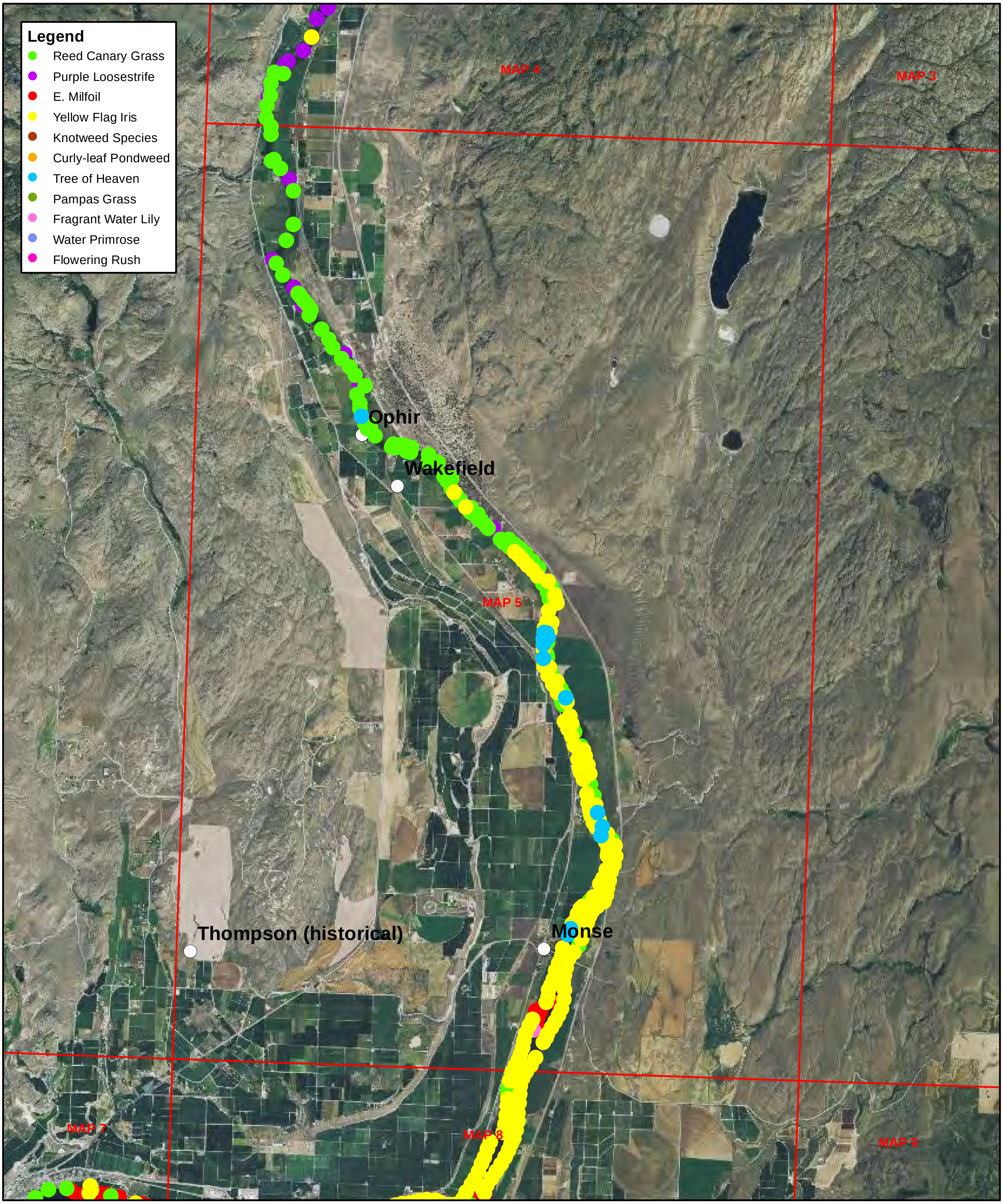
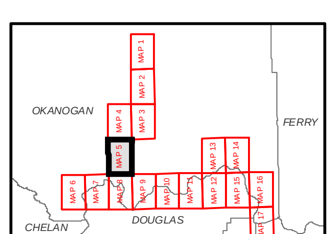


Okanogan County
Weed Control Survey 2014

MAP 5

0 1 2 Miles

MAP EXTENT



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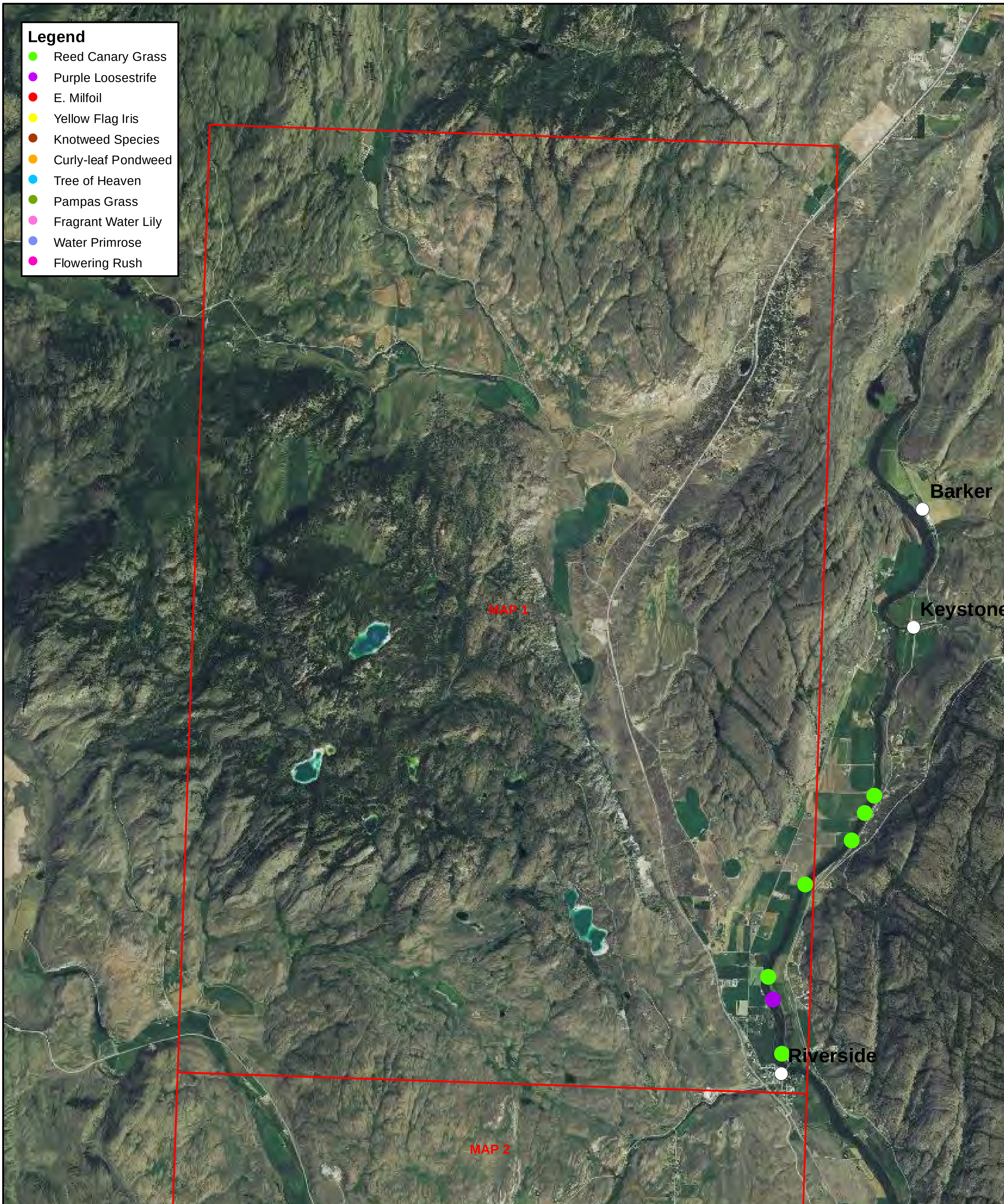
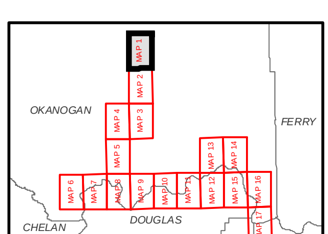


Okanogan County Weed Control Survey 2014

MAP 1

0 1 2 Miles

MAP EXTENT



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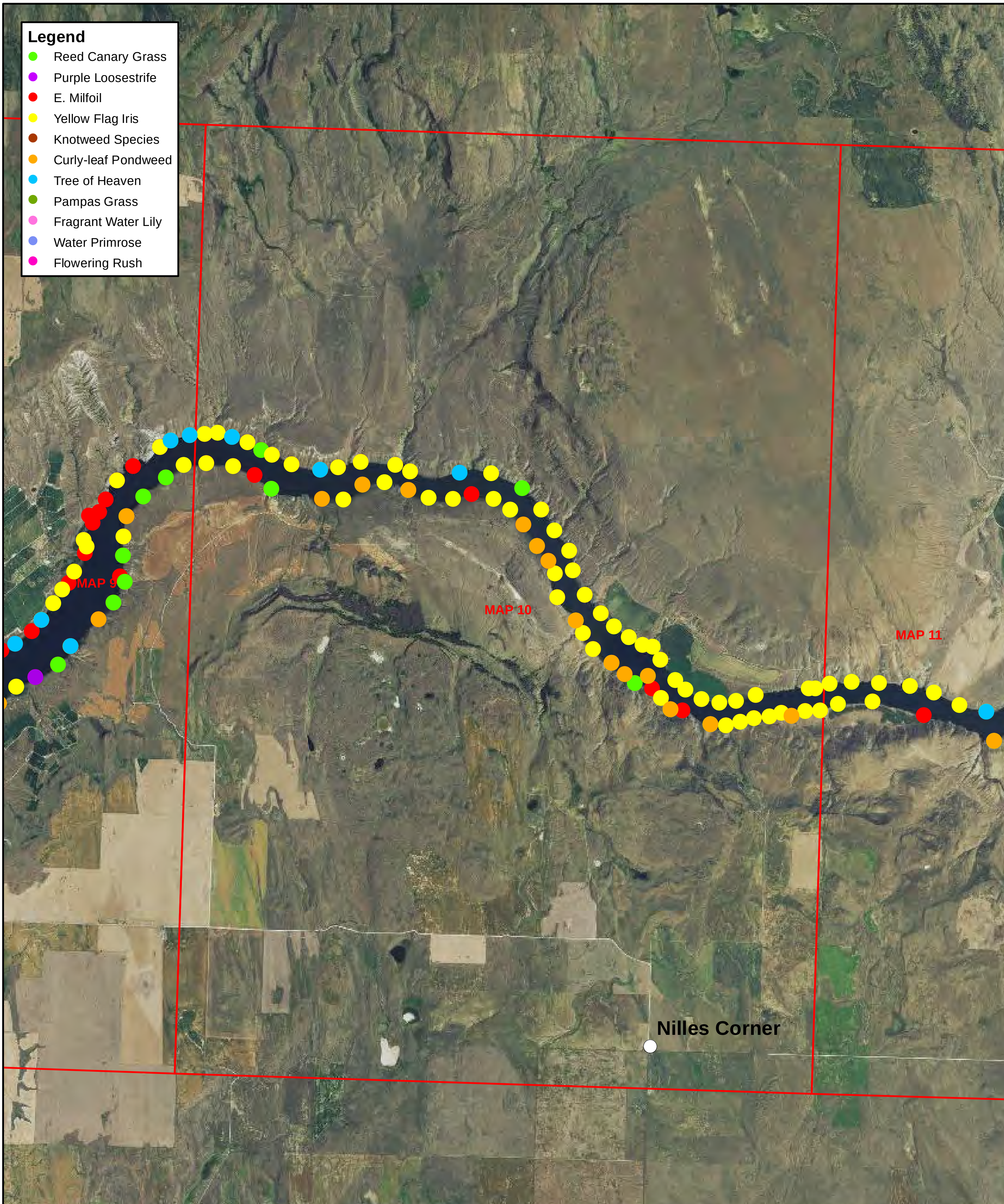
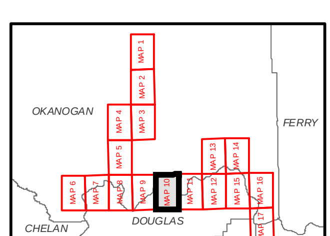


Okanogan County
Weed Control Survey 2014

MAP 10

0 1 2 Miles

MAP EXTENT



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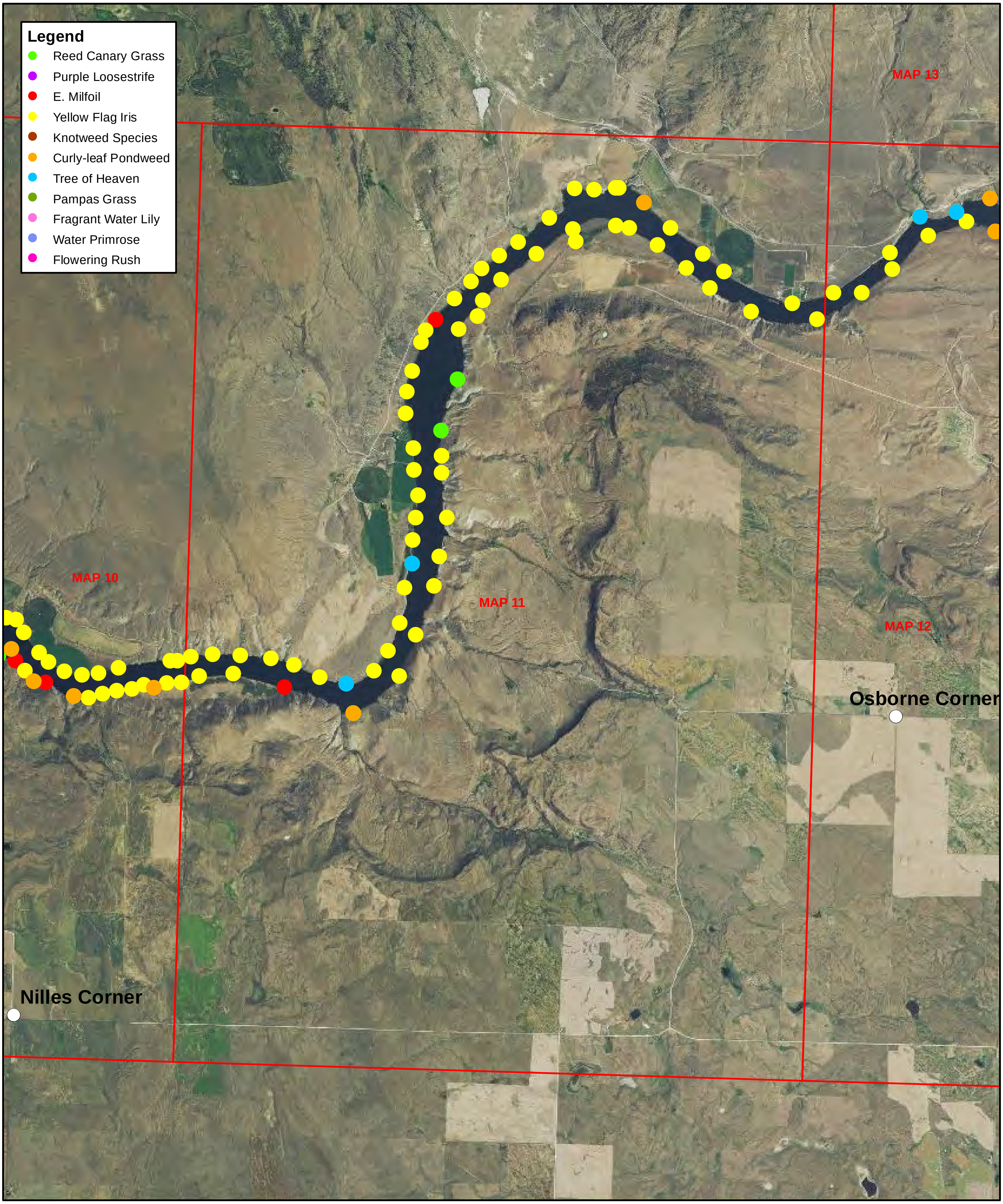
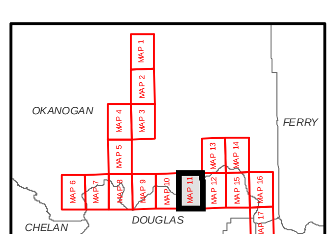


Okanogan County Weed Control Survey 2014

MAP 11

0 1 2 Miles

MAP EXTENT



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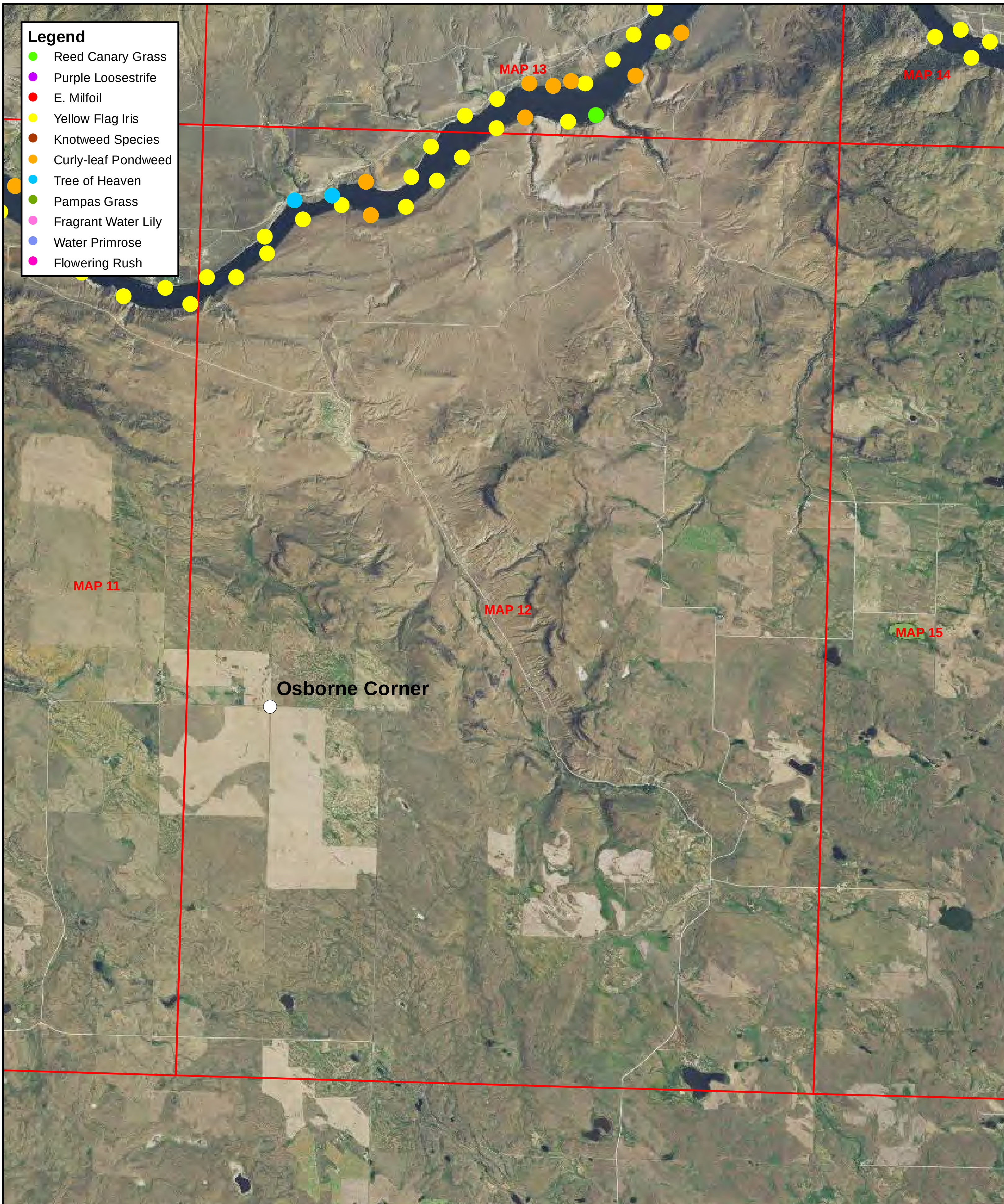
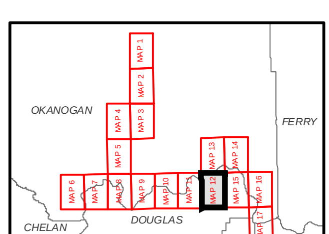


Okanogan County
Weed Control Survey 2014

MAP 12

0 1 2 Miles

MAP EXTENT



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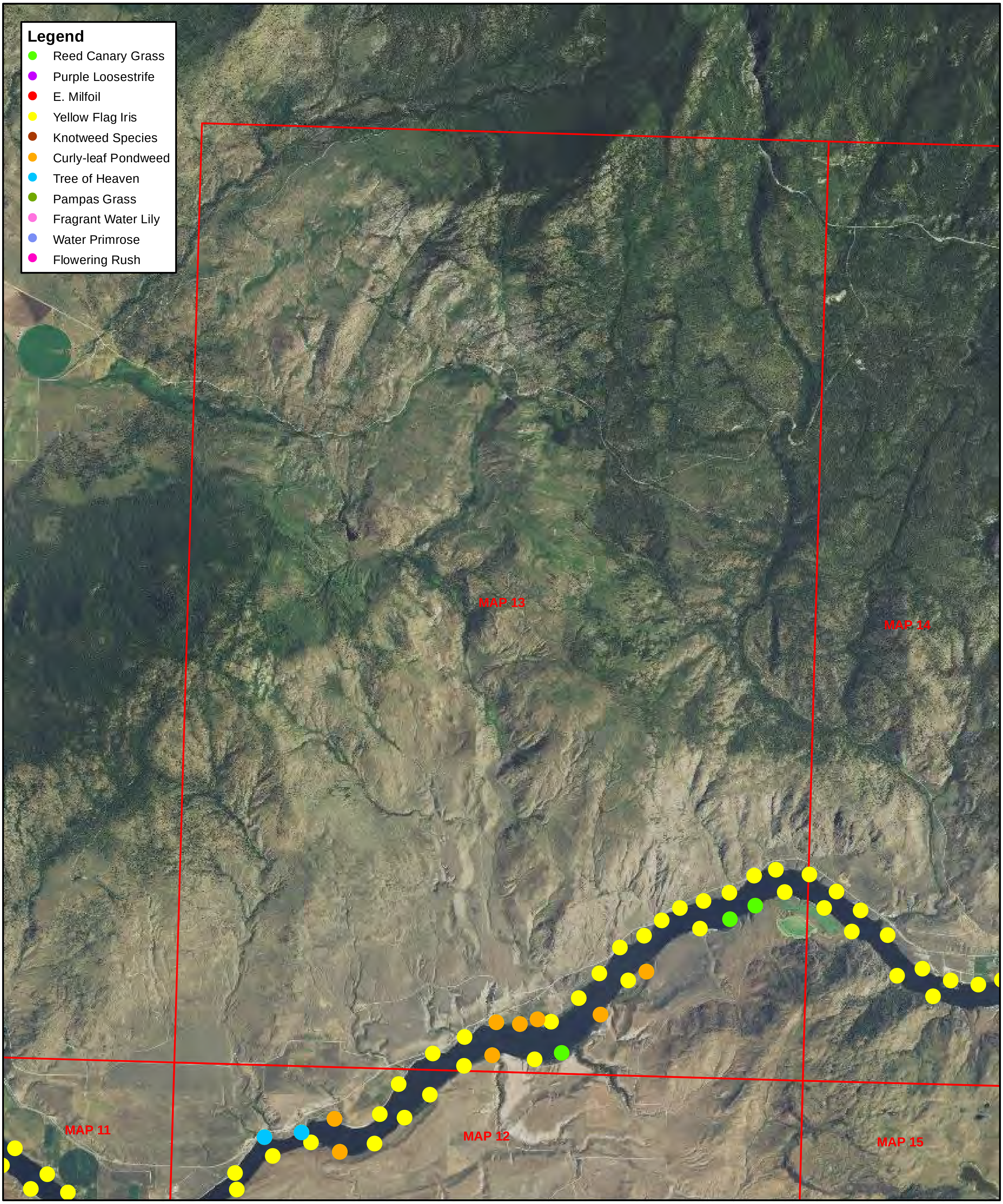
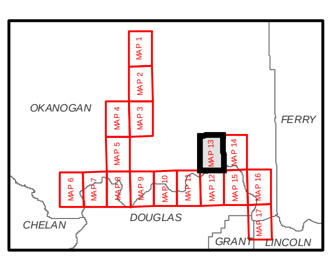


Okanogan County
Weed Control Survey 2014

MAP 13

0 1 2 Miles

MAP EXTENT



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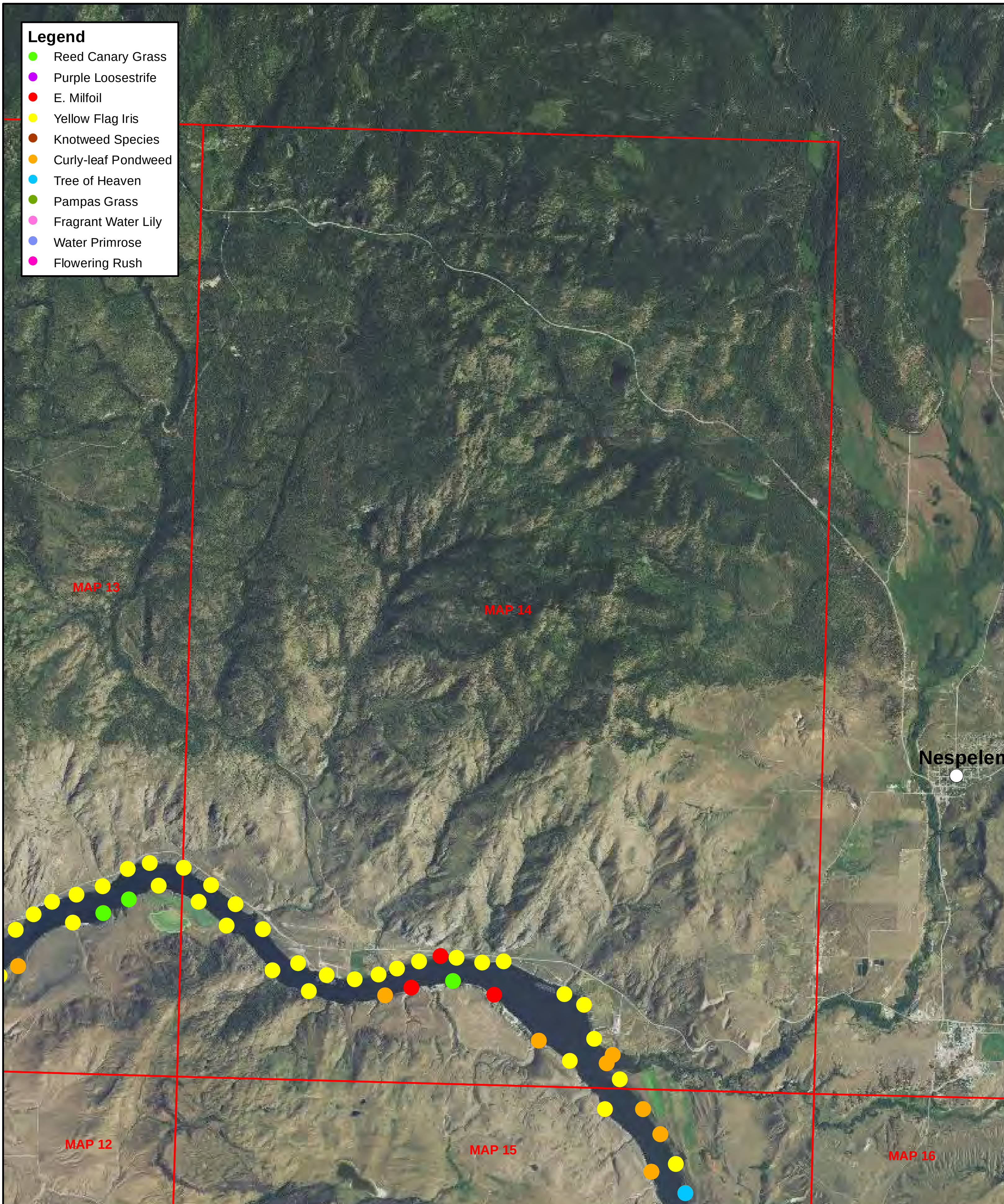
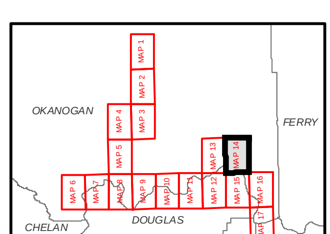


Okanogan County
Weed Control Survey 2014

MAP 14

0 1 2 Miles

MAP EXTENT



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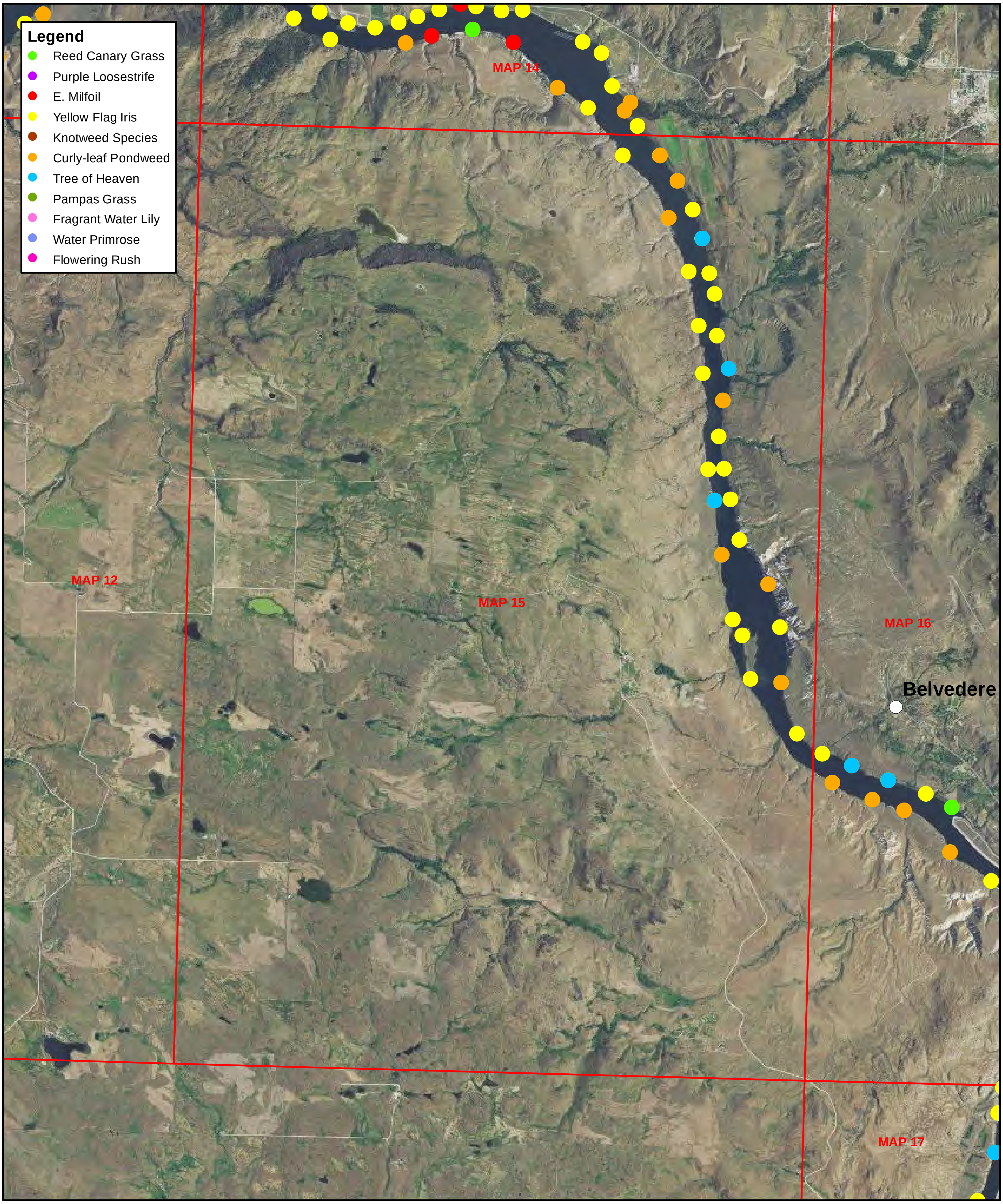
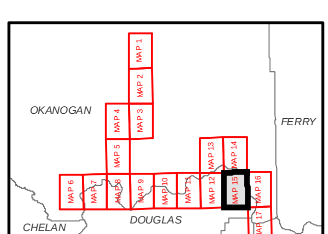


Okanogan County
Weed Control Survey 2014

MAP 15

MAP EXTENT



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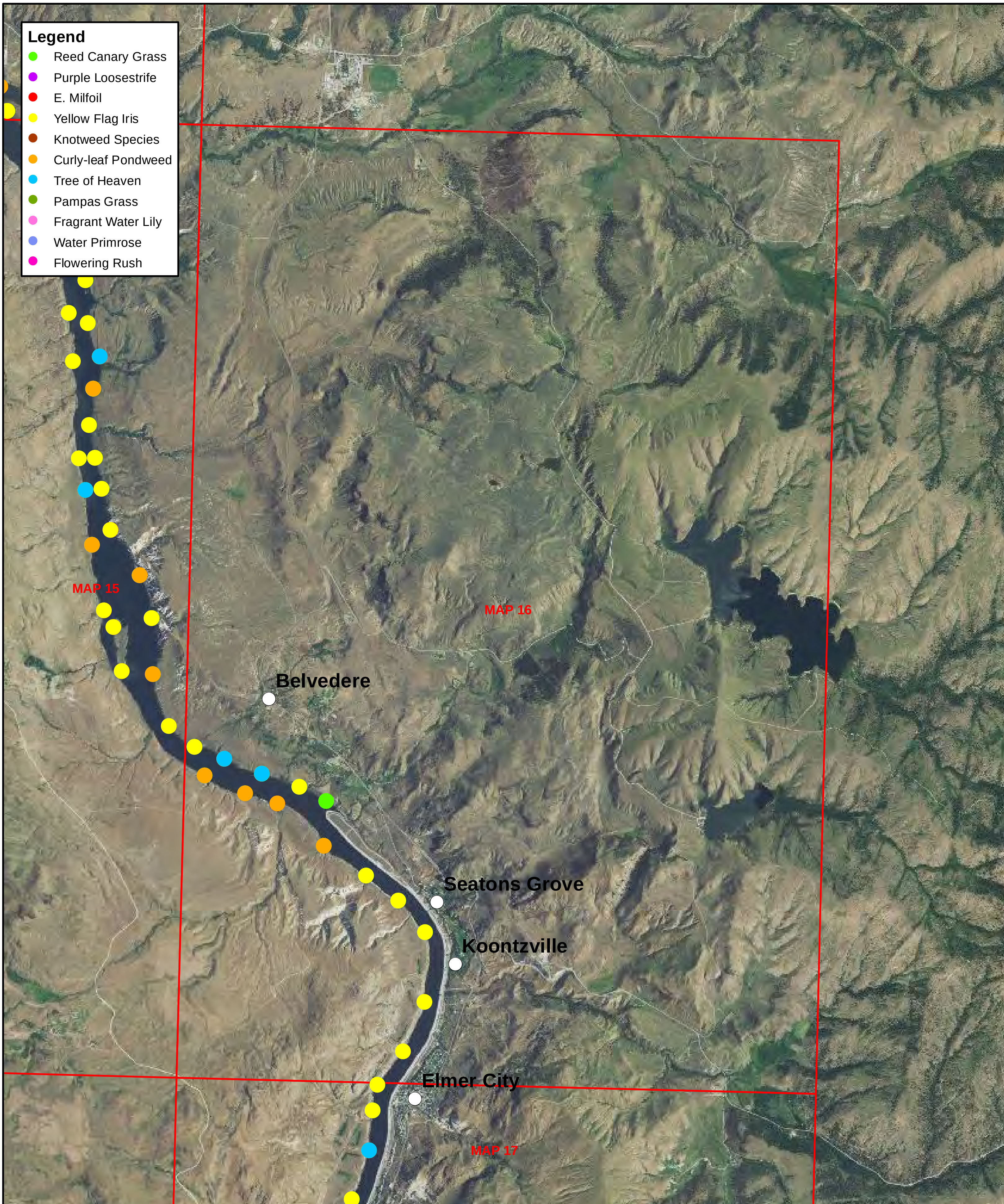
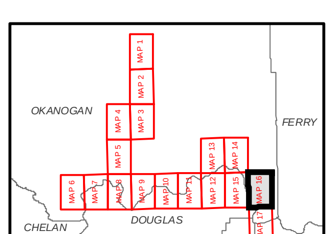


Okanogan County Weed Control Survey 2014

MAP 16

0 1 2 Miles

MAP EXTENT



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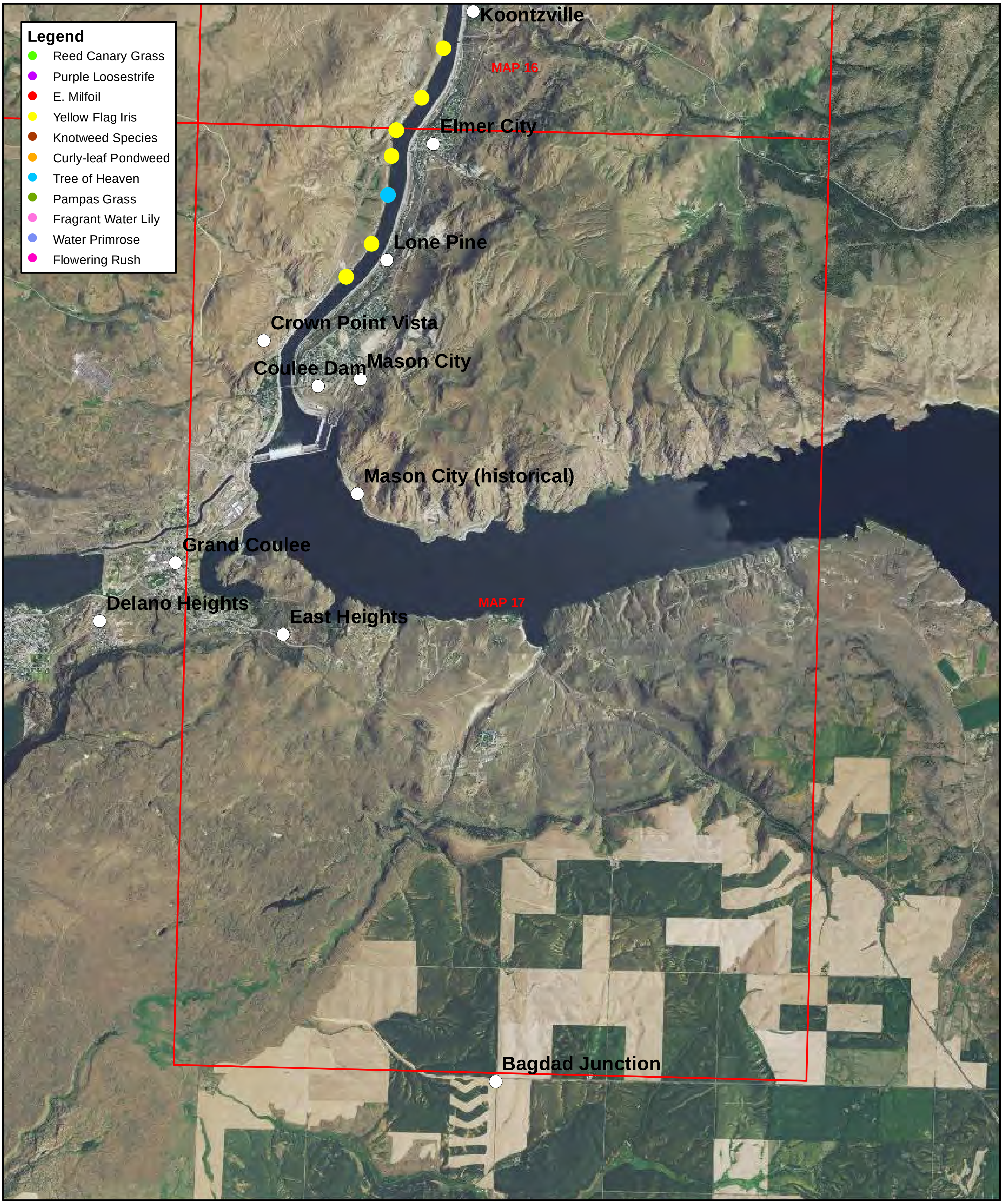
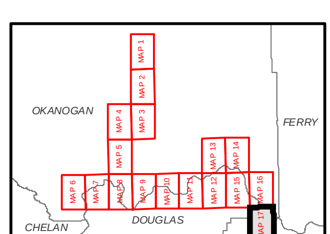


Okanogan County
Weed Control Survey 2014

MAP 17

0 1 2 Miles

MAP EXTENT



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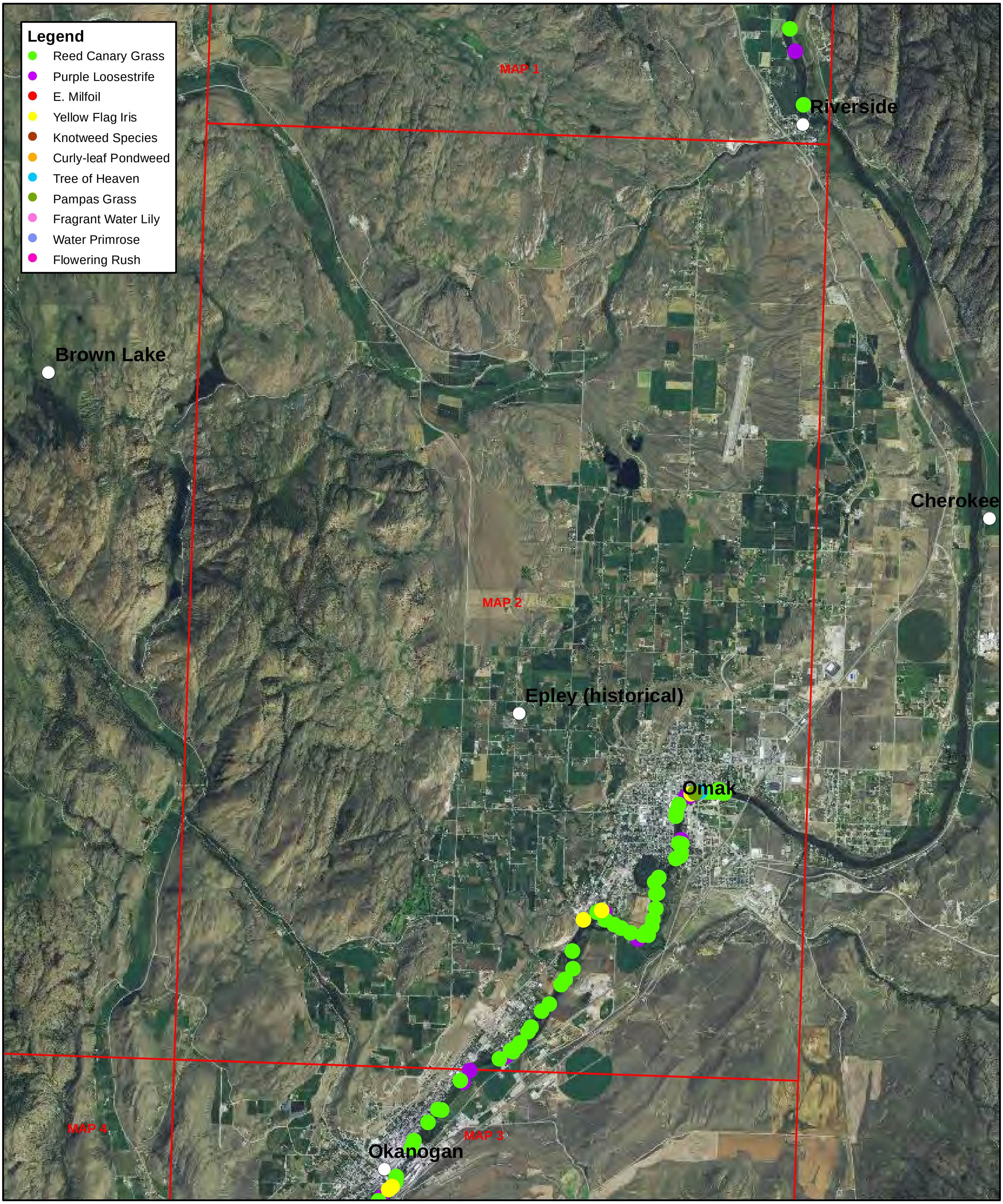
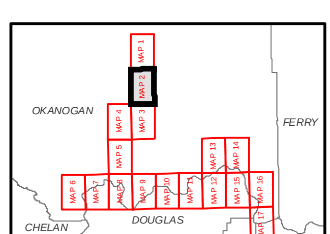


Okanogan County Weed Control Survey 2014

MAP 2

0 1 2 Miles

MAP EXTENT



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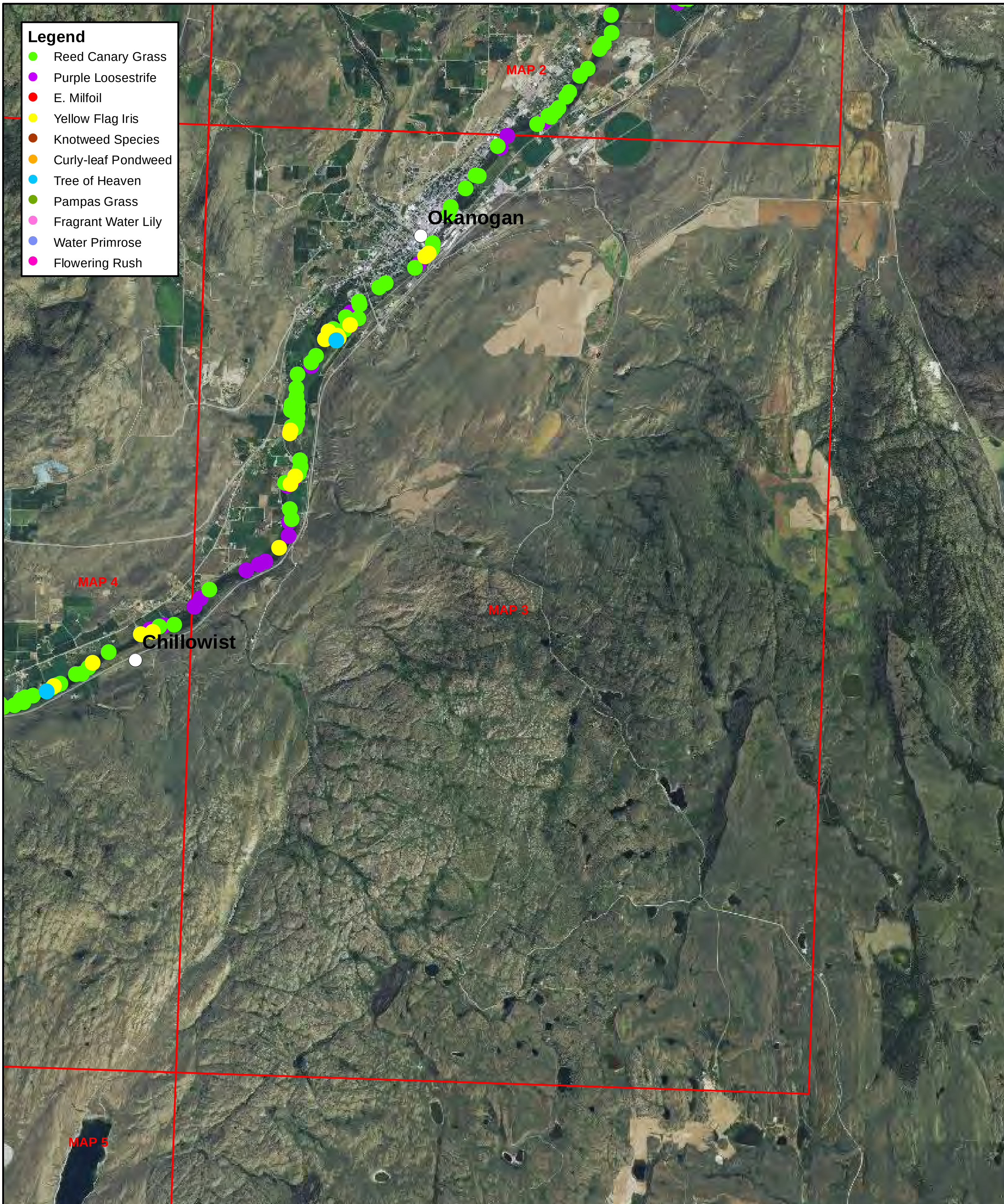
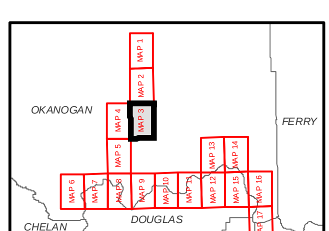


Okanogan County
Weed Control Survey 2014
MAP 3

0 1 2 Miles

MAP EXTENT



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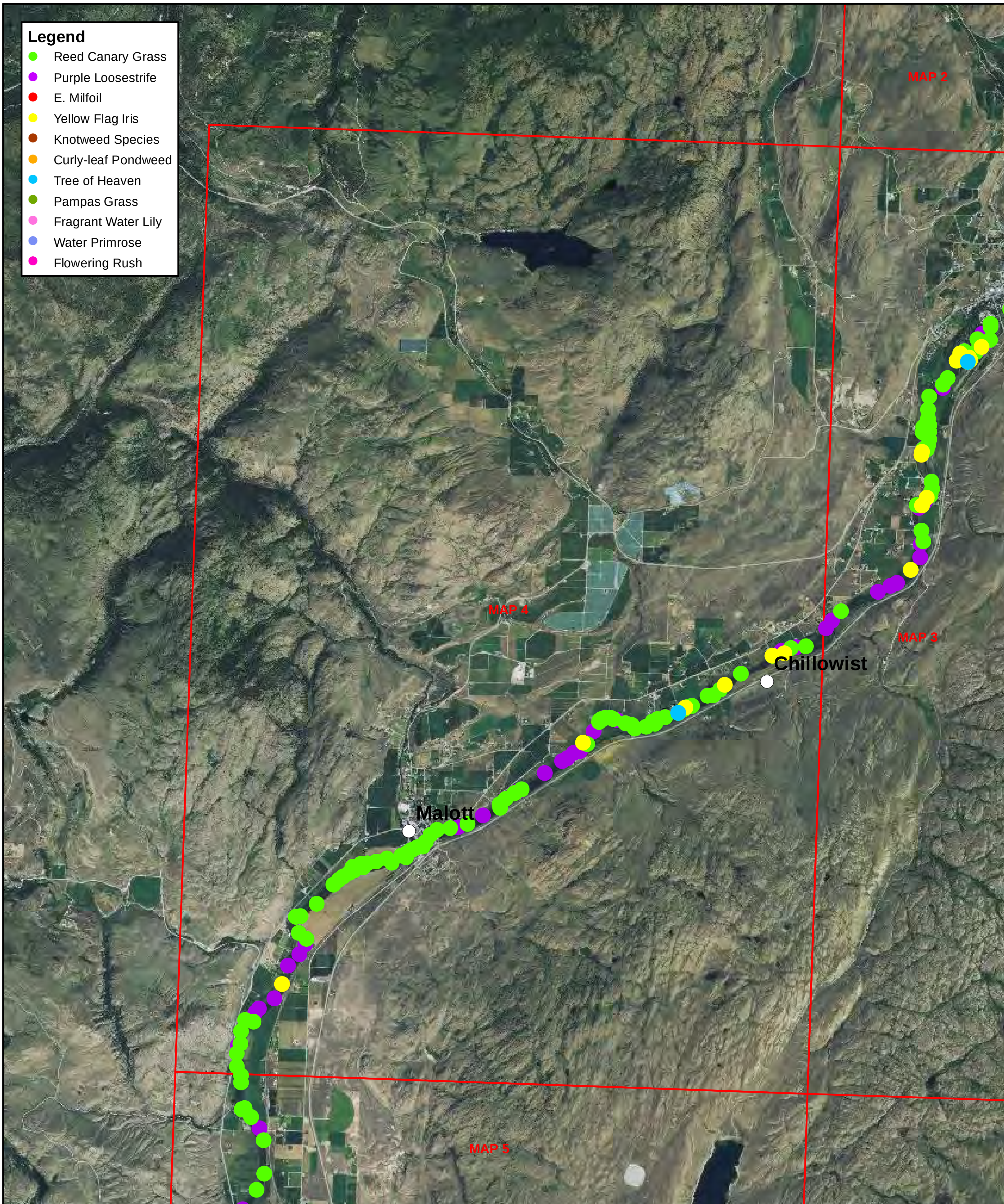
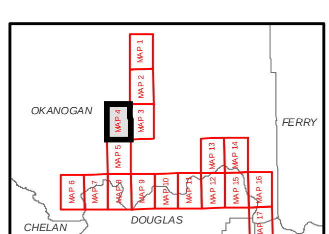


Okanogan County Weed Control Survey 2014

MAP 4

0 1 2 Miles

MAP EXTENT



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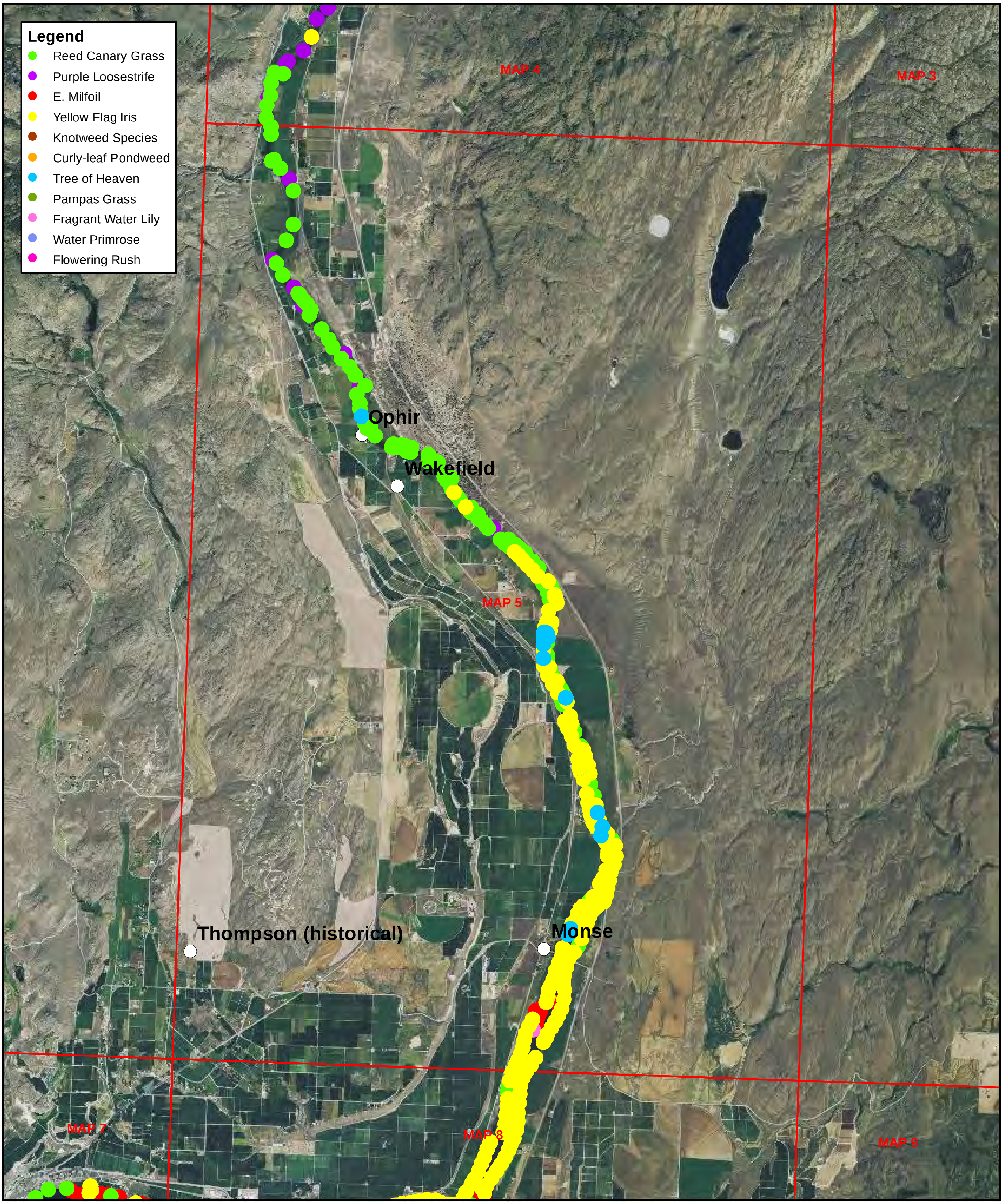
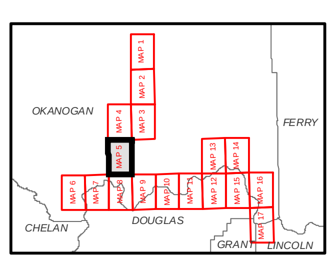


Okanogan County
Weed Control Survey 2014

MAP 5

0 1 2 Miles

MAP EXTENT



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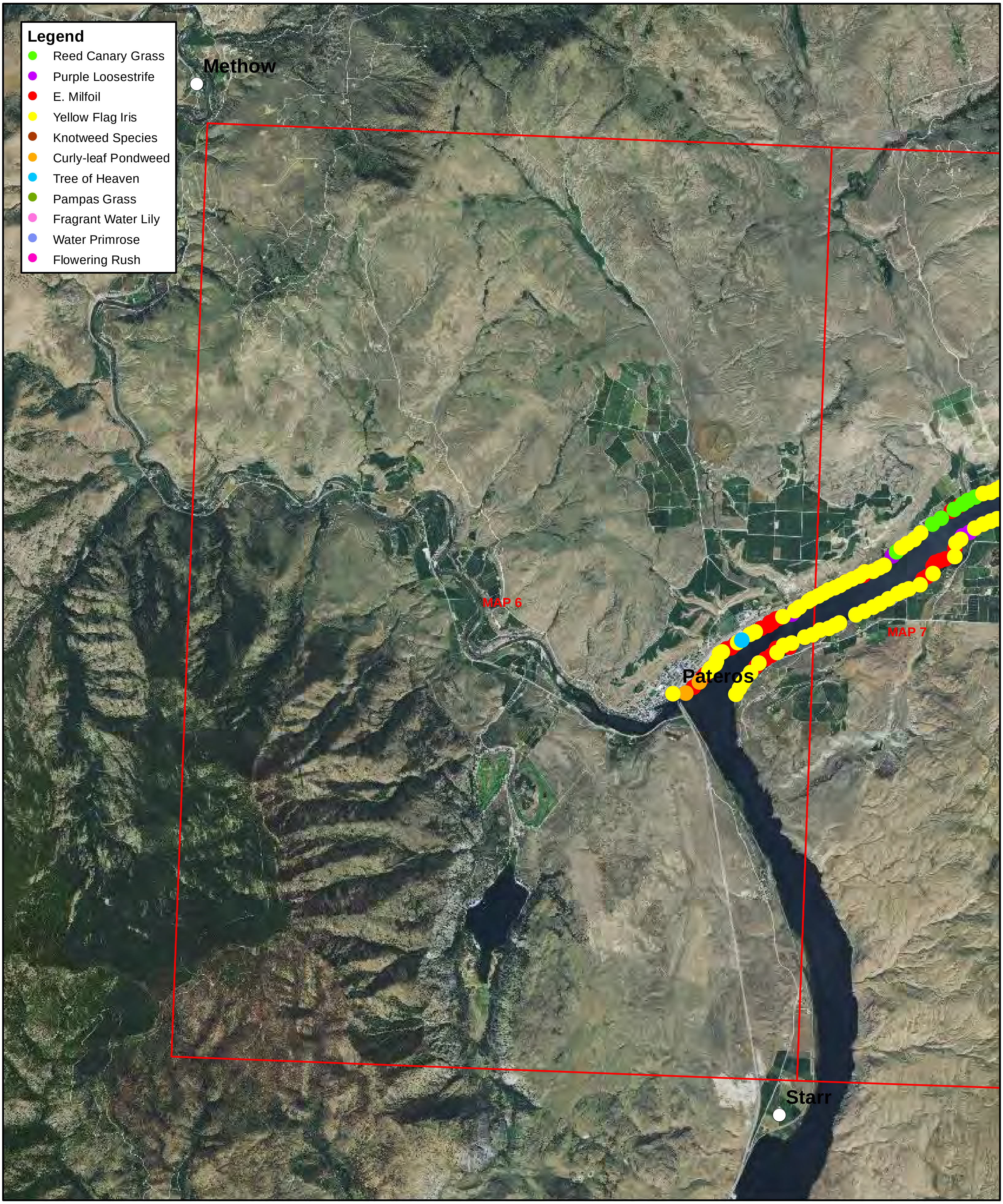
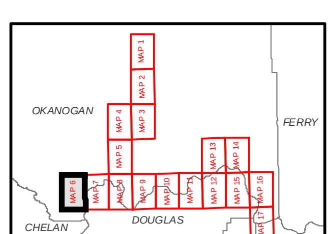


Okanogan County
Weed Control Survey 2014

MAP 6

0 1 2 Miles

MAP EXTENT



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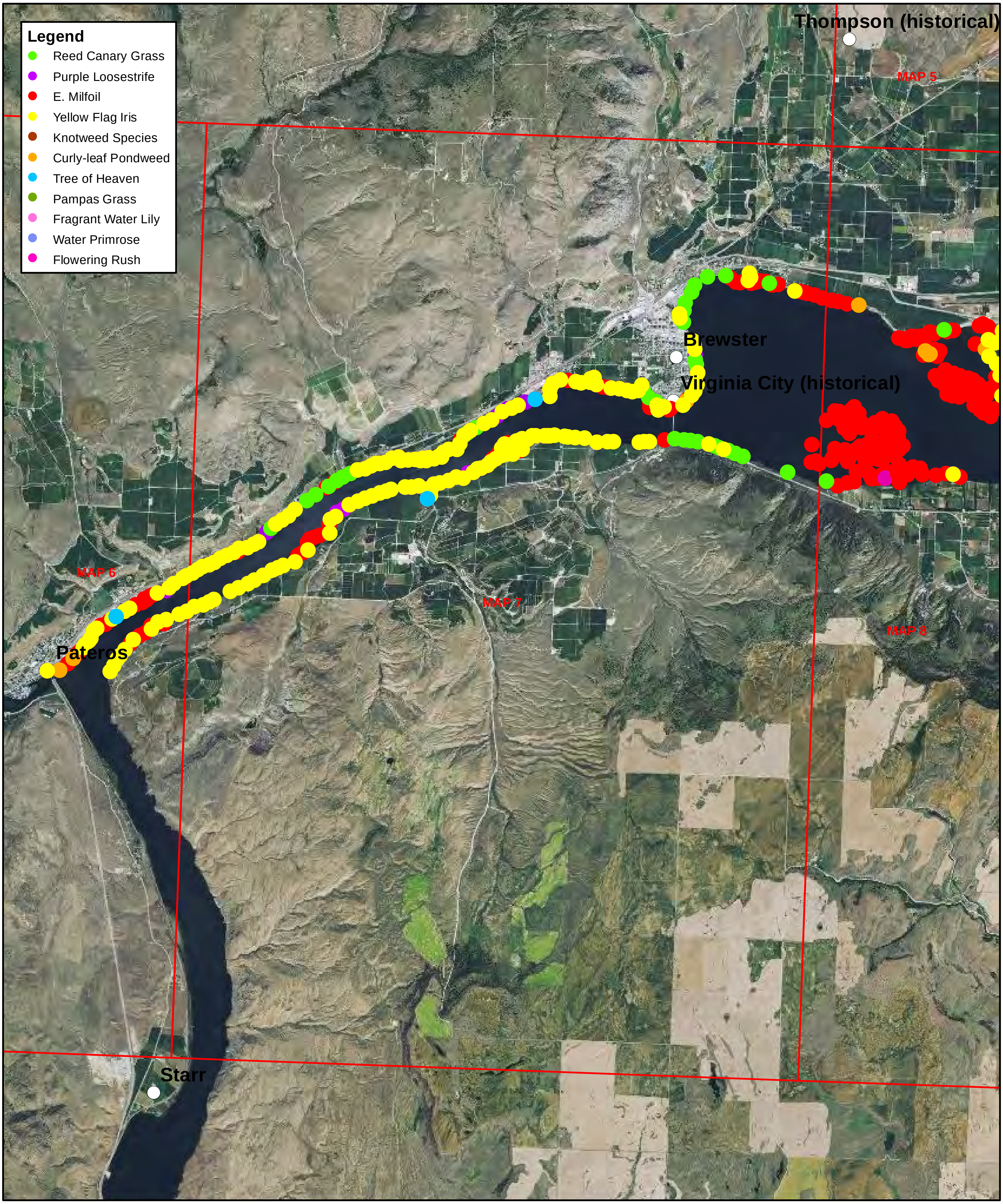
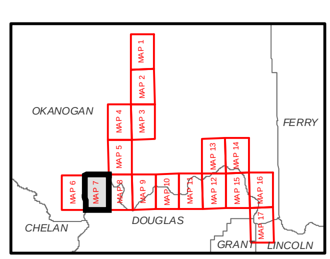


Okanogan County
Weed Control Survey 2014

MAP 7

0 1 2 Miles

MAP EXTENT



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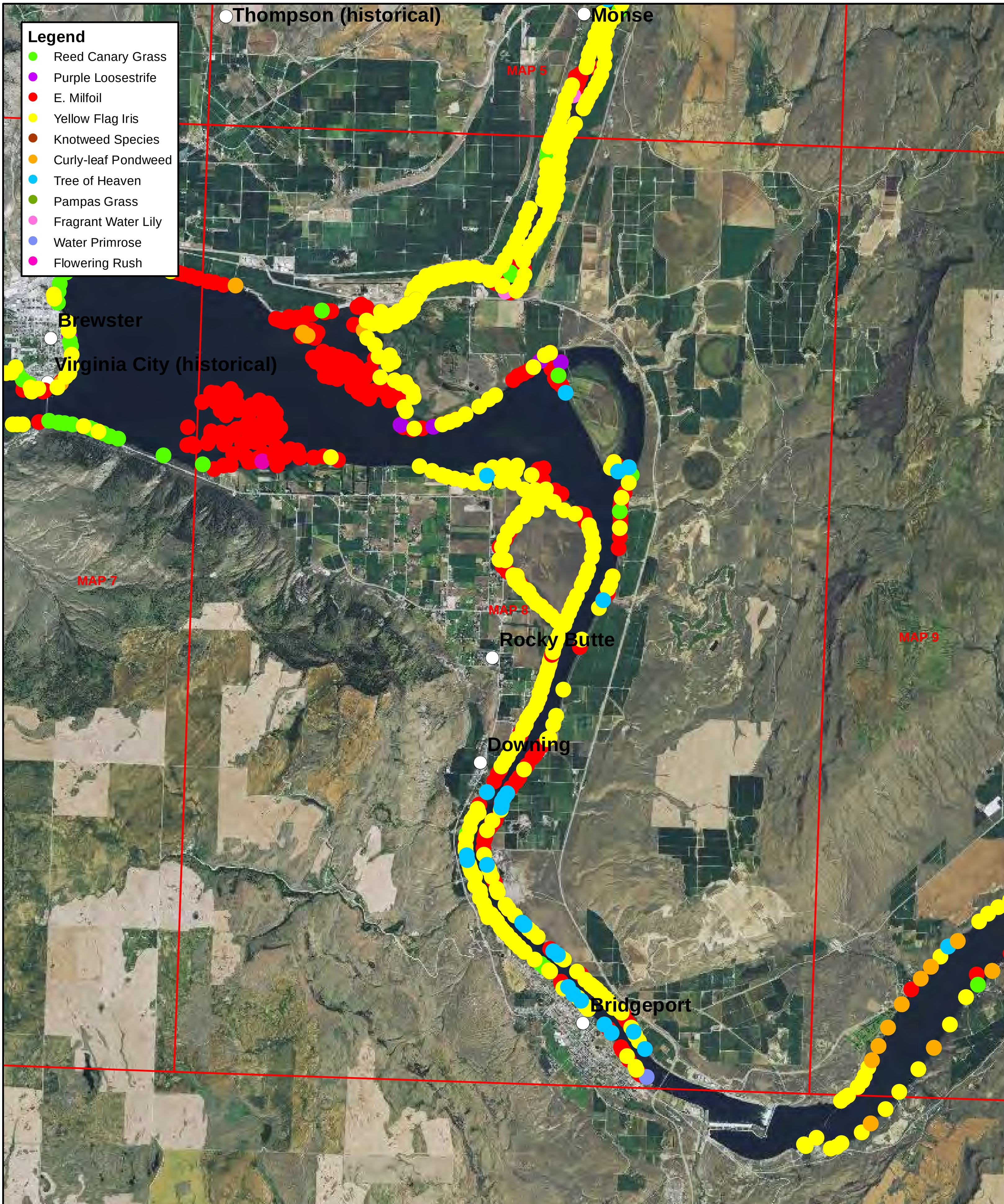
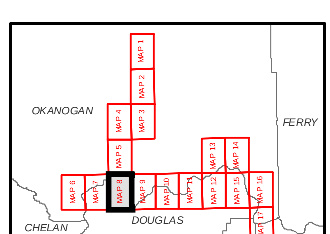


Okanogan County
Weed Control Survey 2014

MAP 8

0 1 2 Miles

MAP EXTENT



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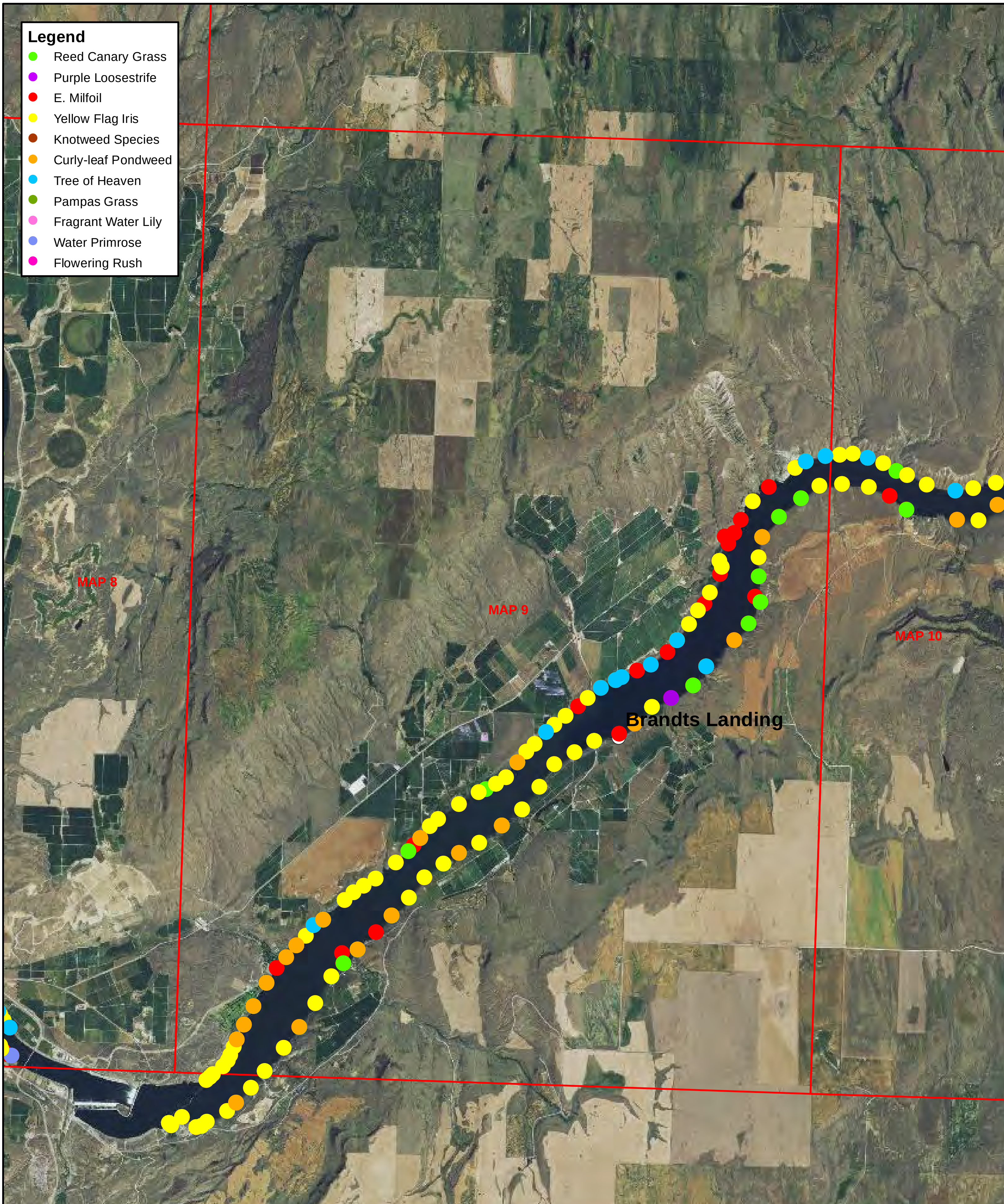
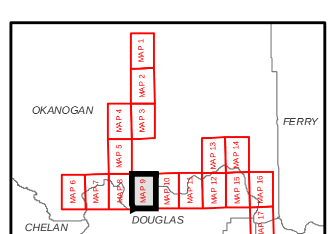


Okanogan County
Weed Control Survey 2014

MAP 9

0 1 2 Miles

MAP EXTENT



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Date: 9/14/2014

LAKE OSOYOOS

INTEGRATED AQUATIC VEGETATION MANAGENT PLAN

2013

Drafted by:
Ford Waterstrat – Lake Osoyoos Association
Anna Lyon – Okanogan County Noxious Weed Control Board

EXECUTIVE SUMMARY

Aquatic noxious weeds are a detriment to the health and water quality of Lake Osoyoos. This plan addresses these aquatic noxious weeds, and targets Eurasian watermilfoil for immediate control. Eurasian watermilfoil (Myriophyllum spicatum or Milfoil) is a submersed aquatic noxious weed that proliferates to form dense mats of vegetation in the littoral zone of lakes and reservoirs. It reproduces naturally by fragmentation, and is often spread as fragments that "hitch-hike" on boat trailers from one lake to another. Excessive fragmentation in Lake Osoyoos has been caused by boaters traveling through Milfoil infestations and the Milfoil harvesting activities occurring north of the border which cause large floating mats that follow the currents down the lake into US waters.

Milfoil can degrade the ecological integrity of a water body in just a few growing seasons. Dense stands of milfoil crowd out native aquatic vegetation, which in turn alters predator-prey relationships among fish and other aquatic animals. Milfoil can also reduce dissolved oxygen – first by inhibiting water mixing in areas where it grows, and then as oxygen is consumed by bacteria during decomposition of dead plant material. Decomposition of M. spicatum also adds nutrients to the water that could contribute to increased algal growth and related water quality problems. Further, dense mats of M. spicatum can increase the water temperature by absorbing sunlight, create mosquito breeding areas, and negatively affect recreational activities such as swimming, fishing, and boating.

Economically there is a significant cost to both reducing the spread of Milfoil and the continued growth of Milfoil in the Columbia River Watershed; of which Lake Osoyoos in an integral part. Various resources indicate that lake front property values can be reduced by 12-25% when impacted by Milfoil. In the Okanagan watershed on the Canadian side of the border, they routinely spend upwards of $300,000 on mechanical harvesting and rototilling for Milfoil control.

Lake Osoyoos, in Okanogan County Washington, is infested with Milfoil. Members of the Lake Osoyoos Association (LOA) realized the potential gravity of the aquatic weed problem and initiated a partnership with the Okanogan County Noxious Weed Control Board (OCNWCB) to apply for an Aquatic Weeds Management Fund grant through the Washington Department of Ecology (Ecology).

Since eradication is very difficult to achieve, and re-introduction is very likely, LOA and the community are organizing a management plan/device to implement ongoing monitoring and spot control. Immediate control measures are needed to protect the regionally significant resource areas of Lake Osoyoos from Milfoil and other invasive aquatic noxious weeds. Since Osoyoos flows into the Okanogan River, reducing milfoil infestations in the lake will contribute to reductions of milfoil in the Okanogan River as well as the Columbia River

This Integrated Aquatic Vegetation Management Plan (IAVMP) is a planning document developed to ensure that the applicant and the community have considered the best available information about the waterbody and the watershed prior to initiating control efforts. Members of LOA and OCNWCB worked in partnership to develop this IAVMP. To tackle the difficult task of generating community concern and action for an environmental issue, a core group of Association members formed a Steering Committee, which included OCNWCB staff members.

Through their work, the Steering Committee was able to educate the wider community about the problem, and inspire them to contribute feedback about potential treatment options. The Association ultimately agreed upon an integrated treatment strategy, which includes a combination of chemical, bio control, and manual, mechanical, and cultural control methods. While there is concern over mechanical methods because of excessive fragmentation which contributes to spread, it is realized that at some point it may be necessary, but it is not considered a first option of control.

This plan presents lake and watershed characteristics, details of the aquatic weed problems at Lake Osoyoos, the process for gaining community involvement, discussion of control alternatives, and recommendations for initial and ongoing control of noxious aquatic weeds threatening the lake.

PROBLEM STATEMENT

Lake Osoyoos contains a total of 5,723 acres of which 2,046 acres are in the United States. The Milfoil, which is harvested in BC Waters, is spread downstream to the US side of the lake and ultimately into the Columbia River Watershed. This, and the current outbreak of Milfoil on the Lake pose a continuing threat of infestation to the watersheds of the Okanogan River and on to the Columbia River. The current outbreak of Milfoil on the lake poses a nuisance, economic, and safety threat to lakeside residents, recreational users, sports fishermen, boaters, and agricultural profitability. This plan will focus on the United States waters. Given that Lake Osoyoos is a main watershed for the Okanogan River which flows downstream to the Columbia, controlling invasive species here is a high priority.

Due to prolific growth of several species of dense, invasive aquatic noxious weeds, Lake Osoyoos is in danger of losing its aesthetic beauty, its wildlife habitat, and its recreational attributes as well as potentially decreasing the profitability of agricultural production. If left untreated, the worst of these weeds, Eurasian water milfoil (Myriophyllum spicatum), will further displace native aquatic vegetation, preventing most recreational uses and eliminating badly needed wildlife habitat. As Engle (Engle 1987) and Newroth (Newroth 1985) point out, there are negative effects for sport fish species such as Large Mouth Bass and Salmonids via reduced spawning success. More specifically, Milfoil can reduce water quality via a number of mechanisms, including increased nutrient loadings; reduce dissolved oxygen and changes in water temperature (Bates et al. 1985; Madsen 1997). In the summer of 2012, there was a significant fish kill in Lake Osoyoos of returning Sockeye salmon created by both the reduction of oxygen and high temperatures which created good conditions for the Columnaris bacteria which Washington Department of Fish and Wildlife (WDFW) confirmed as the of cause of the salmon kill. There will be long-term financial and recreational loss and the loss of conservation areas, all affecting watershed residents and other members of the public who use the lake for recreation and angling purposes. Increasing development in the area is likely to increase the number of people using the lake in coming years, which accelerates the magnitude of the loss of beneficial uses to the community.

The shallow shoreline areas of Lake Osoyoos provide an excellent habitat for aquatic plants and wildlife. Aggressive, non-native Eurasian water milfoil (milfoil) has invaded the lake and is colonizing much of the near-shore aquatic habitat. The dense submersed growth of milfoil has begun to cause a significant deterioration in the quality of the lake and its value to the community. The boat launch area has dense patches of milfoil, which can spread to other lakes by fragments on boat trailers. Milfoil patches have been found crowning the water surface in areas that are 15’-18’ in depth, and fragmentation by boaters is causing its further spread.

Milfoil is the most significant submersed invasive threat but other noxious weeds have also invaded Lake Osoyoos. These include Fragrant water lily (Nymphaea odorata), Purple loosestrife (Lythrum salicaria), Curlyleaf pondweed (Potamogeton crispus) and Yellow flag iris (Iris pseudacorus). All of these species are considered noxious weeds as listed in WAC 16-750. None of the native aquatic plants in the system are a management issue at this time. The native plants provide important benefits to the aquatic system and are not impeding any of the recreational uses of the lake. Removing the noxious invaders will reduce the degradation of the system and allow the dynamic natural equilibrium to be re-established.

Unfortunately, these invasive plants concentrate in the near shore zone which is also that portion of the lake that is valued and utilized most by lake residents and visitors. Dense weed growth poses a threat to swimmers, and the portion of the lake where people can fish is shrinking. Milfoil, Curly leaf pondweed and Fragrant water lilies foul fishing gear, motors, and oars. It is no longer possible to troll through large portions of the lake.

As a group these invasive plants:

- Pose a safety hazard to swimmers and boaters by entanglement

- Snag fishing lines and hooks, eventually preventing shoreline fishing
- Crowd out native plants, creating monocultures lacking in biodiversity
- Significantly reduce fish and wildlife habitat, thereby weakening the local ecosystem as well as degrading wildlife and wildlife viewing opportunities
- Pose a threat to adjoining ecosystems
- Impact oxygen levels in the lake
- Threaten a re-emerging Sockeye salmon run
- Pose a threat to the profitability of agriculture

The Lake Osoyoos Association has worked diligently to control invasive weeds through non chemical means and without the large scale use of a mechanical harvester. They have not been able to meet the current challenge of controlling such widespread infestations or of preventing re-infestation. Immediate action is necessary to control Eurasian water milfoil and other invasive weeds. If left unchecked, the lake will soon become heavily infested with aquatic weeds, severely degrading the lakes' ecosystem and making them even harder to eradicate with significant impact downstream. The Association recognizes that after initial control efforts, opportunity for re-infestation must be minimized.

MANAGEMENT GOALS

The primary management goal is to control noxious aquatic weeds in Lake Osoyoos in a manner that allows sustainable native plant and animal communities to thrive; maintains acceptable water quality conditions, and facilitates recreational enjoyment of the lake.

There are four main strategies to ensure success in meeting this goal:

1. Involve the community in each phase of management process;
2. Use the best available science to identify and understand likely effects of management actions on aquatic and terrestrial ecosystems prior to implementation;
3. Review the effectiveness and sustainability of management actions;
4. Adjust the management strategy as necessary to achieve the overall goal.

COMMUNITY INVOLVEMENT

From the very beginning, members of LOA and landowners in the surrounding area have demonstrated their commitment to improving their community and protecting the lake as well as the expansive natural areas around their homes. This section provides an overview of past, present, and future of community involvement.

Community History

Osoyoos has a total perimeter of 29.8 miles. Lake Osoyoos is mainly fed by the Okanagan River watershed in Canada.

Most of the Okanagan River basin watershed lies north of the Canadian border, where its flow is regulated by four lakes along the river's mainstream. Most of these lakes are located north of the U.S.-Canada border except the 14,150-acre Osoyoos Lake, which straddles the border. The lower Okanogan River flows out of Osoyoos Lake (elevation 915' m.s.l.) at the city of Oroville and flows 79 miles southward to its confluence with the Columbia River (779' m.s.l.). The Similkameen River joins the Okanogan River just downstream of Oroville, where its flow is increased by an average of 400 percent. About 20 small tributary streams also drain into the Washington portion of the basin. Most of the tributaries are small or intermittent, contributing little to the overall flow of the lower Okanogan River.

Newspaper accounts state that Eurasian Milfoil was introduced into Okanagan Lake system in the early 1970's and has proven to be extremely disruptive to B.C's lake ecosystems.

The idea of having a Lake Osoyoos Association (LOA) began in October of 1983. The LOA was incorporated in 1984 with fifteen board members. The stated mission of the LOA was to represent the interests of its members in the stewardship of Lake Osoyoos.

At its first meeting in 1984 residents were polled as to their concerns. The continued growth of Milfoil was number one. The number two issue was water levels in the lake. At this time there were 39 paid members in the LOA.

The LOA participated in one of the first meetings in this area with the Washington Department of Ecology Interagency Task Force on Milfoil Control in December of 1983.

Much of the early work of the LOA concerned a dispute between the Department of Natural Resources (DNR) and the "line of ordinary high water." This issue was discussed for much of 1983 to 1987 with a final agreement after much input from the LOA in 1987. Also at this time there was concern regarding plans for the City of Vernon BC to dump untreated sewage into the Okanagan system.

In March of 1984, a trial of 2-4 D was tried in Lake Osoyoos on the U.S. side of the border. A newspaper article in the Osoyoos Times on March 24th stated that, "The U.S. Army Corps of Engineers, which is carrying out the tests, also believe the new way of applying 2-4 D could almost eliminate the problem of spreading milfoil from drifting weed segments." This was attempted in the belief of trying to stop the spread of milfoil downstream into the Okanogan River and ultimately the Columbia River. As John Spencer, then director of the Washington State Ecology Department stated about that attempt, "We were wrong." The spread downstream continued.

1984 also marked the first use of a "weed harvester" on the Canadian side of the lake. At this time the Department of Ecology view of harvesting was, "...the machines as something that probably worsens attempts downstream to handle milfoil because harvesting breaks off more fragments that drift; then restart themselves further on."

The LOA supported improvement in the Boat Tax in the 1985 legislature. In April of 1985 the LOA also had support from the Army Corps of Engineers for continued use of 2-4 D which they (LOA) supported.
However, in August of 1985 the Eurasian Milfoil control program was suspended due to an injunction issued by the Federal Court.

Harvesting and now rotovation occur as the Canadians main method of dealing with Milfoil to this date. This despite much data that finds that harvesting, rotovation, wave action, and boat traffic all produce milfoil fragments. In fact, Crowell, Troeslrup Jr, Queen, and Perry (J. Aquat. Plant Manage. 32: 56-60) found that harvested plots had significantly "higher relative growth rates over the remaining field season," than did non-harvested areas.

An Osoyoos Times Newspaper article in July of 1987 stated "that after years of harvesting; ...the weeds have come back with a vengeance this year". In 1987, the budget for harvesting in the Okanagan watershed was $147,000. Today it is upwards of $500,000.

In a bit of an ironic twist, a University of Victoria student spent three summers (1984-1987) studying the possibility of using biological control methods to augment the mechanical control methods. To this day the Canadians only use mechanical means to deal with milfoil**.**

In 1984 the LOA supported the rebuilding of the Zosel Dam in Oroville as a way to better control lake levels.

After the 1987 Federal injunction against the use of 2-4 D and the settlement of the water level issues the LOA involvement in lake issues waned with the exception of dealing with how the international border on the lake would be marked in 1992, and with water quality monitoring. As a result of this, in 1994 the Department of Ecology determined that Lake Osoyoos was found to have high forms of the pesticide DDT; which were found at levels that violate state standards.

In 1996 there were 200 lake shore land owners on Lake Osoyoos. In the LOA's 2011 membership drive membership brochures were sent out to 250 lake shore owners.

In 2005-2006 the LOA was involved in issues of property rights and lake shore development. There have been recent developments on the US side of Lake Osoyoos with the establishment of the Veranda Beach Resort on close to 900 acres, much of it set back from the lake with access to the lake.

Members of the LOA have conducted bi-monthly water quality testing from May to September on the lake since 2007. The ongoing Milfoil problem has also been an area of concern and members had repeatedly contacted OCNWCB for information regarding control options.

In 2010, the LOA along with the OCNWCB wrote and applied for a Department of Ecology Planning grant. In 2011, at their annual meeting they had representatives from the Department of Ecology, OCNWCB, and Enviroscience present to discuss treatment options, with a focus on bio-controls.
In 2011 and 2012 the LOA and OCNWCB participated in cross border meetings with members of the Christina Lake Water Society. In addition, LOA members participated in the Osoyoos Water Science Forum in 2011, in Osoyoos, B.C. During the summer of 2012 the LOA met with a representative of Enviroscience in Oroville to talk about what would be involved in doing a substantial pilot project on the lake along the U.S. Canadian Border. They even received a plan by Enviroscience for such a project. However, at that time they could not get the Canadians to agree to split costs for the project and there were questions raised on the Canadian side of the border regarding the re-introduction of the weevils back into the lake of origin and possible introduction of other invasive species.

During 2012 the LOA and OCNWCB had several meetings with the Mayor of Osoyoos, B.C. and the Okanagan Basin Water Board to talk about the use of biological control. This discussion even talked about the possibility of raising and propagating weevils in their Sterile Insect Release facility. While there was much interest in this possibility initially from the Canadians, problems with the economic sustainability of the SIR facility tabled further discussion. However, during the course of the Ecology grant work, the LOA was able to work with the Oroville High School Science Lab to perform a small pilot project regarding rearing and releasing the weevil on its own.

Community commitment

Community outreach and involvement by the Lake Osoyoos Association has included the establishment of a LOA webpage (lakeosoyoosassoc.com), monthly newsletters from April to November, public meetings, dissemination of educational materials at Oroville's May Day celebration, partnership with the local High School science lab in keeping fish tanks with milfoil and weevils. In addition, the LOA has distributed Milfoil signage at public boat launches on the lake. During weekend in the summer of 2013, informational brochures regarding Eurasian watermilfoil, and Quagga and Zebra mussels distributed to recreationists in both of Oroville's City Parks. LOA members have participated in WALPA and NALMS conventions. The LOA had a large membership drive sending information to all landowners on the U.S. side of the lake, including Canadians.

In 2012 the LOA worked to develop a sustainable partnership with our neighbors north of the border. We participated in their Water Science Forum which was sponsored by the Town of Osoyoos, and several other organizations on both sides of the border. During this time we had substantive meetings with the Okanagan Water Board Society and the Mayor of Osoyoos. These discussions talked about common concerns around milfoil and included the discussion of using biological control.

At the end of the summer of 2012 the town of Osoyoos in a good faith effort contributed a substantial amount of money to our LOA to work on water quality efforts in the lake.

During the summer of 2012 LOA members, with the guidance of Jennifer Parsons from Ecology, began to identify and collect weevils for the purpose of attempting to propagate weevils. With money from our planning grant and with the assistance of Anna Lyon of the OCNWCB, we purchased ten twenty gallon fish tanks, aerators, lights, and thermometers, and set up a lab in the Oroville High School science lab. We followed the practices outlined by Alfred F. Cofrancesco, Holly Crosson, August 1999, Vol A-99-3, US Army Corps of Engineers, and reviewed the process published by Jennifer Parsons, the Department of Ecology, from her work in 2002-2003. All practices were similar in nature and easily modified to suit individual projects.

LOA community members then went out on the lake in July 2012, spending several days, and collected weevils, took them and milfoil to the fish tanks in the science lab. Propagation was confirmed by Jennifer Parsons in August. LOA members then took 15+ weevils to a small protected area with dense milfoil. The area was marked with a buoy. Later monitoring of this area noted a distinctive lowering of milfoil in the water column.

Also in July to August 2012 Sockeye Salmon passing through the lake were dying off in large numbers. The LOA contacted the Fish and Wildlife Department who sent an officer out and documented the kill as due to the Columnaris bacteria which affects their gills.

The LOA also participated in discussion regarding the renewal of the cross-border agreement concerning lake levels for 2013.

PUBLIC CONSENSUS

The increasing amount of Eurasian watermilfoil and other aquatic noxious or nuisance weeds has caused a community to agree that control efforts must occur to ensure recreational safety and water quality. To date, there have been no objections to the proposed project or for the proposed methods of treatment from local landowners. Every person who has learned about the project has voiced support.

Given the community's small size, and their dedication and enthusiasm for keeping Lake Osoyoos healthy, none of the Steering Committee members anticipate resistance to the proposed project prior to, during, or after implementation.

CONTINUING COMMUNITY EDUCATION

The Lake Osoyoos Association will offer the means by which the community will receive ongoing education. In addition, the Steering Committee for the proposed aquatic weed removal project will remain intact, although membership on the Steering Committee is likely to change over time. To ensure that community education is consistent with best available science and water quality standards, the Association will continually educate themselves by maintaining contact with aquatic professionals. Information will be disseminated through community club meetings, watershed mailings when applicable, and the Association newsletter. Additionally, the Association will work to recruit new lake monitors and surveyors. An Association website was developed and now includes information about Eurasian watermilfoil. All of the documents and PowerPoint presentations generated by the Steering Committee meetings will be available for download.

The public education program for Lake Osoyoos will consist of three elements that will be implemented concurrently:

1. **Noxious Aquatic Weeds Prevention and Detection -** Initial control efforts are only worth doing if future infestations are prevented, or detected and controlled soon after detection. Since the re-introduction of milfoil and other weeds to Lake Osoyoos is almost certain, a prevention and detection plan is essential.

The LOA web site will be used to distribute educational materials. Steering Committee members will compile published materials and generate literature specifically related to Lake Osoyoos to make it available to all lake residents each year at the beginning of the growing season on the LOA website. Pictures for identification purposes will be added to the web site to raise awareness among individual landowners of potential non-native invasive plants. A better-educated community of residents and lake-users will be more likely to identify and report noxious aquatic weeds and other potential problems. These educational materials will also be available through area businesses that support recreational opportunities on the lake.

2. Lake Stewardship Education Program - All residents on the Lake affect the water quality of Lake Osoyoos, although sometimes the cause and effect relationships are not readily apparent. Educating community members and other lake users will illuminate the relationship between human behaviors and water quality. Each lake resident will be provided information on how to reduce the amount of pollutants entering the lake from their property. Property owners with lakeside lots will be provided information on lake-friendly landscaping, subsequently ensuring a healthier lake environment. Improved signs will be posted at the boat ramp to inform lake-users of the problems caused by noxious aquatic weeds and how to prevent spreading them from lake to lake.

3. Two aquatic weed surveys each growing season. Volunteers (community members) will undergo training with lakes/aquatic plant specialists prior to conducting surveys. There is a core of committed volunteers who will be trained in plant collection using a double sided rake. They will be trained to survey the lake bottom using this technique to complement visual surveys from the surface and to take samples for identification

WATERSHED AND WATERBODY CHARACTERISTICS

Watershed Characteristics

The Okanogan River Watershed encompasses about 2,100 square miles in Washington State. This watershed extends north and south from the Canadian border to the Columbia River. The physical northern boundary of the watershed is actually in the Canadian province of British Columbia where another approximately 6,000 square miles is located. Mean precipitation over the Okanogan River Watershed is 15 inches.

The Okanogan River flows through Osoyoos Lake, which extends across the international boundary, and continues southward to empty into the Columbia River near Brewster. However, an even greater inflow from Canada is from the Okanogan's major tributary, the Similkameen River. The Similkameen crosses the border west of the Okanogan and enters the Okanogan River near the south end of Osoyoos Lake. About 2.1 million acre-feet of water enters the watershed from Canada as streamflow; about 75 percent of this amount is from the Similkameen River. The outflow from the watershed at Brewster is estimated to be 2.2 million acre-feet.

This watershed is within the Columbia Basin, Cascades, and Northern Rockies ecoregions. The eastern and western boundaries of the basin are steep, jagged ridgelines at elevations ranging from 1,500 feet to more than 5,000 feet above the basin floor. The floodplain of the Okanogan River valley averages about a mile in width, and descends from an elevation of about 920 feet at the international boundary to about 780 feet at the river's confluence with the Columbia River. Osoyoos Lake occupies the northern most 4 miles of the valley floor and extends several miles into Canada.

The soils in the watershed include shallow to moderately deep sandy loam and silt loam. These soils are formed from volcanic ash and pumice (ejected from Glacier Peak to the west centuries ago), glacial till and outwash, alluvium, lake sediments, and wind-laid silts.

There are approximately 32,855 people living in the Okanogan Basin. The primary population centers are Omak and Okanogan. The majority of people live in unincorporated areas. The largest land uses in the basin are forested lands (51%) and agricultural lands (39%).
(Okanogan County Planning & Development website)

Waterbody Characteristics

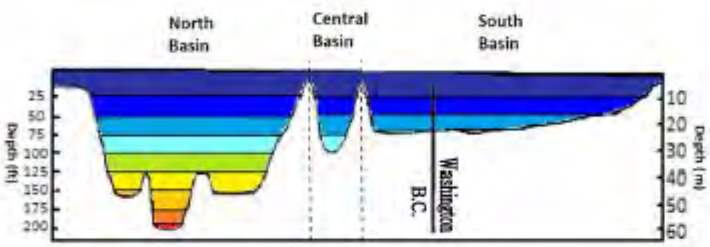


Figure 2. Cross-sectional view of Osoyoos Lake, illustrating depths for the north basin, central basin, and south basin. Modified from Hyatt et al. (personal communications, 2007). Note that the south basin is shallower here than in Figure 3, which was based on earlier bathymetric data.

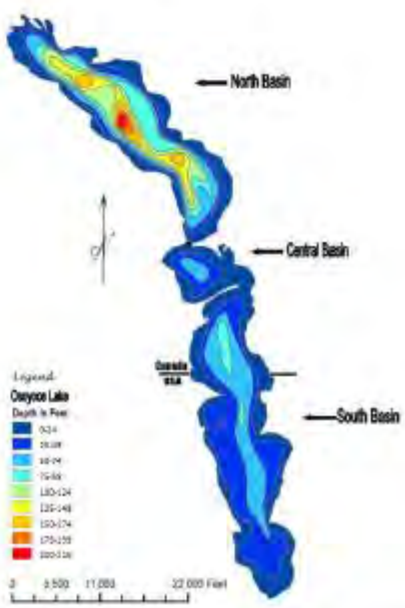


Figure 3. Bathymetry contour map of Osoyoos Lake. Updated from ArcGIS and Anglers Atlas, 2002. Map survey conducted August 1966 by the Province of British Columbia.

6

This big beautiful lake is ten miles long, covers 5729 surface acres and is split by the United States / Canadian border. British Columbia owns 3693 of these surface acres and the rest are in Washington State. Osoyoos has a total perimeter of 29.8 miles. Lake Osoyoos is mainly fed by the Okanagan River watershed in Canada.

Most of the Okanagan River basin watershed lies north of the Canadian border, where its flow is regulated by four lakes along the river's mainstream. Most of these lakes are located north of the US / Canada border except the 5,800 –acre Osoyoos Lake which straddles the border. The lower Okanogan River flows out of Osoyoos Lake (elevation 915’ msl) at the city of Oroville and flows 79 miles southward to its confluence with the Columbia River (779’ msl). The Similkameen River joins the Okanogan River just downstream of Oroville where its flow is increased by an average of 400%. About 20 small tributary streams also drain the 2,600 miles of the Washington portion of the basin. Most of the tributaries are small or intermittent, contributing little to the overall flow of the lower Okanogan River.

Osoyoos is touted as the warmest lake in Canada; the water’s temperature reaches a bath tub warmth of 78 – 80 F in August. In August, the air temperature can soar to the low 100’s.

Given that the lake is in the Sonora Desert region the lake can quickly develop high winds; in 2007 there was a sustained wind burst of 71 MPH. In the summer of 2012 there were sustained winds of 53 MPH. When the milfoil is blooming the wave action created by these large winds can create more fragments floating on the waves, further distributing the milfoil.

Water levels of Lake Osoyoos have been regulated by the IJC (International Joint Commission) since 1946, when it approved alterations to an existing dam downstream from the lake. Under orders of the IJC, a new structure was constructed in 1987 to replace the dam. The orders set maximum and minimum lake elevations of 911.5 and 909 feet during normal years. During a drought year, water may be stored to lake elevations as high as 913 feet.

The five kinds of fish in the lake make it a hit with fishermen, with species including Large Mouth Bass, Trout and Kokanee. In the summer of 2012, there was a large sockeye salmon return (upwards of 300,000). Due to the high water temperatures and low oxygen levels, especially on the US side of the border, hundreds of these Sockeye developed a Columnaris bacteria and died off.

Water Quality

Data reported by the Washington State Department of Ecology in 1997:
TROPHIC STATUS
Estimated Trophic State: Mesotrophic
Mean Trophic State Index (Secchi): 41 (Oligo-mesotrophic)
Mean Trophic State Index (Total Phosphorus): 42 (Mesotrophic)
Mean Trophic State Index (Chlorophyll a): 42 (Mesotrophic)

SUMMARY AND EXPLANATION OF TROPHIC STATE ASSESSMENT
Although TSI values suggest an oligo-mesotrophic assessment, summertime hypolimnetic DO concentrations show a lake that is nearly anoxic in the hypolimnion. All factors considered, a mesotrophic assessment is most suited for Lake Osoyoos.

Fish and Wildlife Communities

Lake Osoyoos and its surrounding habitats support a variety of fish, birds, and animals by providing nesting, forage, and cover. According to Washington Department of Fish and Wildlife (WDFW) the resident fish species in Lake Osoyoos include anadromous salmonids, pygmy whitefish; rainbow trout; sockeye; spring Chinook; summer Chinook; summer steelhead; and multiple species of sunfish.

Mink, beaver, muskrat, ducks, loons, lizards, frogs, and salamanders are also present in Lake Osoyoos. Geese, Bald Eagle, Common Loon and Western Grebe are also associated with the lake which is in their migratory path.

Beneficial and Recreational Uses

Lake Osoyoos and its surroundings support a variety of uses to humans. Recreational activities include swimming, fishing, boating, bird watching, and wildlife viewing. Residents access the lake for these activities from any of the small private docks around the lake associated with the residential parcels. A public boat launch maintained by the City of Oroville allows everybody to benefit from this beautiful resource as well.

Characterization of Aquatic Plants in Lake Osoyoos

The plant communities in, and around Lake Osoyoos, represent a diverse set of ecotypes. Hundreds of species occur in specific habitats represented in the area. The aquatic vegetation serves a wide array of functions, such as supporting food chains, providing habitat for a variety of animal species, intercepting sediment and removing toxic compounds from runoff, and providing erosion control/bank stabilization for lakes and streams.

The most recent comprehensive aquatic plant survey of Lake Osoyoos occurred in 2011 and was performed by DOE. Unfortunately there is no corresponding GIS information of the survey. A Eurasian Watermilfoil survey was conducted in 2010, by Aquatechnex, to determine the extent of infestations. The Lake Osoyoos Association membership has also provided invaluable assistance in detecting emergent vegetation.

Thirty-six plant species (see Table 1) were identified at Lake Osoyoos, including thirteen emergent types, four floating types, and nine sub-mergent types. Emergents are plants that are rooted in the sediment at the water's edge but have stems and leaves which grow above the water surface. Floating rooted plants are rooted in the sediment and send leaves to the water's surface. Sub-mergent plants are either freely-floating or are rooted in the lake bottom but grow within the water column.

Lake Osoyoos continues to support milfoil throughout the littoral zone, including areas of dense concentration. Lythrum salicaria is scattered on the East and South end of the Lake. No significant infestations have been found in the core of the wetland. Populations and distribution of L. salicaria have been partially contained by repeated releases of biological controls

Plant surveys of Lake Osoyoos were carried out in 1993, 2005, 2009, 2010, and 2011. Native plants include several pondweed species, Cattails, sedges, Coontail and Northern watermilfoil. The Washington Natural Heritage Program (WNHP) has a Natural Heritage Information System database for rare plant species, select rare animal species, and high quality wetland and terrestrial ecosystems. This database has species in the vicinity of Lake Osoyoos and Okanogan County (See Attached).

Noxious Aquatic Weeds in Lake Osoyoos

Non-native species include several Washington State listed noxious weeds, such as Yellow flag iris, Purple loosestrife, Curly leaf pondweed, Eurasian watermilfoil, Fragrant water lily and Reed canary grass. These species will be the focus of the plant management efforts on Lake Osoyoos. The term "noxious weed" refers to those non-native plants that are legally defined by Washington's Noxious Weed Control Law (RCW 17.10) as highly destructive, competitive, or difficult to control once established. Noxious weeds have usually been introduced accidentally as a contaminant, or as ornamentals. Non-native plants often do not have natural predators (i.e. herbivores, pathogens) or strong competitors to control their numbers as they may have had in their home range.

WAC 16.750 sets out three classes (A, B, C) of noxious weeds based on their distribution in the state, each class having different control requirements. County Weed Boards are given some discretion as to setting control priorities for Class B and C weeds. Eurasian watermilfoil and Purple loosestrife are both Class B Noxious Weeds, while Fragrant water lily, Curly leaf pondweed, Reed canarygrass and Yellow flag iris are Class C Noxious Weeds.

Eurasian watermilfoil (Myriophyllum spicatum)

Eurasian watermilfoil is native to Europe, Asia, and North Africa and also occurs in Greenland (Washington State Noxious Weed Control Board, 1995). The oldest record of Eurasian watermilfoil in Washington is from a 1965 herbarium specimen collected from Lake Meridian, King County. It was first identified causing problems in the 1970s in Lake Washington and proceeded to move down the I-5 corridor, probably transported to new lakes on boats and trailers. Eurasian watermilfoil is among the worst aquatic pests in North America. M. spicatum is a submersed, perennial aquatic plant with feather-like leaves. It usually has 12 to 16 leaflets (usually more than 14) on each leaf arranged in whorls of 4 around the stem. Leaves near the surface may be reddish or brown. Sometimes there are emergent flower stalks during the summers that have tiny emergent leaves. This plant forms dense mats of vegetation just below the water's surface. In the late summer and fall, the plants break into fragments with attached roots that float with the currents, infesting new areas. Disturbed plants will also fragment at other times of the year. A new plant can start from a tiny piece of a Milfoil plant. Milfoil starts spring growth earlier than native aquatic plants, and thereby gets a "head start" on other plants. Eurasian watermilfoil can degrade the ecological integrity of a water body in just a few growing seasons.

Dense stands of Milfoil crowd out native aquatic vegetation, which in turn alters predator/prey relationships among fish and other aquatic animals. Eurasian watermilfoil can also reduce dissolved oxygen – first by inhibiting water mixing in areas where it grows, and then as oxygen is consumed by bacteria during decomposition of dead plant material. Decomposition of M. spicatum also releases phosphorus and nitrogen to the water that could increase algal growth. Further, dense mats of Eurasian watermilfoil can increase water temperature by absorbing sunlight, raise the pH, and create stagnant water mosquito breeding areas. Eurasian watermilfoil will negatively affect recreational activities such as swimming, fishing, and boating. The dense beds of vegetation make swimming dangerous, snag fish hooks, and inhibit boating by entangling propellers or paddles and slowing the movement of boats across the water. In Osoyoos Lake, M. spicatum is generally moderate in density, but there are an increasing amount of dense infestations.

It is likely that the non-native milfoil infestations will continue to expand if left untreated, dramatically increasing negative impacts to the beneficial uses of Lake Osoyoos.

Purple loosestrife (Lythrum salicaria)

Purple loosestrife is native to Europe and Asia and was introduced through ship ballast water to the Atlantic Coast in the mid-1800s (Washington State Noxious Weed Control Board, 1997). In Washington, Purple loosestrife was first collected from the Seattle area in 1929 from Lake Washington. Purple loosestrife is a perennial that can reach 9 feet tall with long spikes of magenta flowers. The flowers usually have 6 petals, and the stems are squared-off.

Vigorous plants can produce over 2 million tiny, lightweight seeds (120,000 per spike) that are easily spread by waterfowl and other animals (Washington State Noxious Weed Control Board, 1997). Although a prolific seeder, purple loosestrife can also spread through vegetative production by shoots and rhizomes as well as by root fragmentation. It has a woody taproot with a fibrous root system that forms a dense mat, keeping other plants from establishing in a space.

Purple loosestrife disrupts wetland ecosystems by displacing native or beneficial plants and animals. Waterfowl, fur-bearing animals, and birds vacate wetland habitat when native vegetation is displaced by Purple loosestrife. Loss of native vegetation results in decreased sources of food, nesting material, and shelter for indigenous waterfowl and animals. Economic impacts are high in agricultural communities when irrigation systems are clogged or when wet pastures are unavailable for grazing. Purple loosestrife is aggressive and competitive, taking full advantage of disturbance to natural wetland vegetation caused by anthropogenic alterations of the landscape. Seed banks build for years since seeds may remain viable for up to 3 years. Mono-specific stands are long-lived in North America as compared to European stands, illustrating the competitive edge loosestrife has over other plant species. Purple loosestrife will disperse further up into the wetland if not controlled.

Fragrant water lily (Nymphaea odorata)

This noxious weed is native to the eastern half of North America (Washington State Noxious Weed Control Board, 2001b). It was probably introduced into Washington during the Alaska Pacific Yukon Exposition in Seattle in the late 1800's. It has often been introduced to ponds and lakes because of its beautiful, large white or pink (occasionally light yellow), many-petaled flowers that float on the water's surface, surrounded by large, round green leaves. The leaves are attached to flexible underwater stalks rising from thick fleshy rhizomes. Adventitious roots attach the horizontal creeping and branching rhizomes.

This aquatic perennial herb spreads aggressively, rooting in murky or silty sediments in water up to 7 feet deep. It prefers quiet waters such as ponds, lake margins and slow streams and will grow in a wide range of pH. Shallow lakes are particularly vulnerable to being totally covered by Fragrant water lilies. Water lily spreads by seeds and by rhizome fragments. A planted rhizome will cover about a 15-foot diameter circle in five years (Washington State Noxious Weed Control Board, 2001b). This can reduce the important open water component in the littoral zone of Lake Osoyoos.

When uncontrolled, this species tends to form dense mono-specific stands that can persist until senescence in the fall. Mats of these floating leaves prevent wind mixing and extensive areas of low oxygen can develop under the water lily beds in the summer. Water lilies can restrict lakefront access and hinder swimming, boating, and other recreational activities. Fragrant water lily infestations are growing increasingly dense in the lower portion of Lake Osoyoos. Recreational activities such as boating, fishing, and swimming will become more difficult. Even canoes can have great difficulty moving across dense floating mats of Fragrant water lily, not to mention entanglement with propellers of boat motors.

Yellow flag iris (Iris pseudacorus)
Yellow flag iris is native to mainland Europe, the British Isles, and the Mediterranean region of North Africa (Washington State Noxious Weed Control Board, 2001a). This plant was introduced widely as a garden ornamental and has also been used for erosion control. The earliest collection in Washington is from Lake McMurray in Skagit County in 1948 (Washington State Noxious Weed Control Board, 2001a). The yellow flowers are a distinguishing characteristic, but when not blooming, it may be confused with Cattail (Typha sp.) or Broad-fruited bur-reed (Sparganium eurycarpum).

Yellow flag iris spreads by both rhizomes and seeds. The plants produce large fruit capsules and corky seeds in the late summer; these seeds are then easily dispersed along the water channel. Several hundred flowering plants may be connected by rhizomes. Yellow flag iris can spread to form dense stands that can exclude even the toughest of our native wetland species, such as Typha latifolia (cattail). This noxious weed has already infested a large area at the south end of the lake and threatens to disperse further up into the wetland if not controlled. In addition to decreasing plant diversity, Yellow flag iris can also alter hydrologic dynamics through sediment accretion along the shoreline. It has been observed in the Okanogan River, both south of Lake Osoyoos and at the delta of Columbia River.

AQUATIC PLANT CONTROL ALTERNATIVES

This section outlines common methods used to control aquatic weeds. Much of the information in this section is quoted directly from the Ecology's website:
http://www.ecy.wa.gov/programs/wq/plants/management/index.html

Additional information is derived from the field experience of the Okanogan County Noxious Weed Control Board, qualified WSDA licensed aquatic herbicide applicators, and conversations with WDFW and DNR aquatic specialists regarding various non-chemical control methods.

Control/eradication methods discussed herein include Aquatic Herbicide, Manual Methods, Bottom Screens, Diver Dredging, Biological Control, Rotovation, Cutting, Harvesting, and Drawdown.

AQUATIC HERBICIDES

Description of Method

Aquatic herbicides are chemicals specifically formulated for use in water to eradicate or control aquatic plants. Herbicides approved for aquatic use by the United States Environmental Protection Agency (EPA) have been reviewed and considered compatible with the aquatic environment when used according to label directions. However, individual states may also impose additional constraints on their use.

Aquatic herbicides are sprayed directly onto floating or emergent aquatic plants, or are applied to the water in either a liquid or pellet form. Systemic herbicides are capable of killing the entire plant by translocation from the foliage or stems and killing the root. Contact herbicides cause the parts of the plant in contact with the herbicide to die back, leaving the roots alive and capable of re-growth (chemical mowing). Non-selective herbicides will generally affect all plants that they come in contact with, both monocots and dicots. Selective herbicides will affect only some plants (usually dicots – broad leafed plants like Eurasian watermilfoil will be affected by selective herbicides whereas monocots like Brazilian elodea and our native pondweeds may not be affected).

Because of environmental risks from improper application, aquatic herbicide use in Washington State waters is regulated and has certain restrictions. The Washington State Department of Agriculture must license aquatic applicators. In addition, because of a March 2001 court decision (Federal 9th Circuit District Court), coverage under a discharge permit called a National Pollutant Discharge Elimination System (NPDES) permit must be obtained before aquatic herbicides can be applied to some waters of the U.S. This ruling, referred to as the Talent Irrigation District decision, has further defined Section 402 of the Clean Water Act. Ecology has developed a general NPDES permit which is available for coverage under the Washington Department of Agriculture for the management of noxious weeds growing in an aquatic situation and a separate general permit for nuisance aquatic weeds (native plants) and algae control. For nuisance weeds
(native species also referred to as beneficial vegetation) and algae, applicators and the local sponsor of the project must obtain a NPDES permit from the Washington Department of Ecology before applying herbicides to Washington water bodies.

Aquatic Herbicides Labeled for use in Washington State (see Appendix D for herbicide labels) based on active ingredient.

Aquatic labeled Glyphosate - This systemic nonselective herbicide is used to control floating-leaved plants like Water lilies and shoreline plants like Purple loosestrife and Yellow flag iris. It is generally applied as a liquid to the leaves. It does not work on underwater plants such as Eurasian watermilfoil. Although glyphosate is a non-selective herbicide, a good applicator can somewhat selectively remove targeted plants by focusing the spray only on the plants to be removed. Plants take several weeks to die. A repeat application is often necessary to remove plants that were missed during the first application. **Note**: there are now several glyphosate products available, but with different trade names now that the patent has expired. Additional surfactants are always added by the applicator for the aquatic formulations to improve the penetration of the leaf cuticle and help the herbicide stay on the plant long enough to be effective. Those that may be used for emergent weed control include X-77, LI-700, and R-11 as approved by the SEPA process. Only LI-700 is approved for Fragrant water lily control under the NPDES permit.

Aquatic labeled 2,4-D – is a systemic, selective herbicide used for the control of Eurasian watermilfoil and other broad-leaved species. It has several aquatic formulations which can be utilized under different circumstances.

Aquatic labeled Fluridone - is a slow-acting systemic herbicide used to control Eurasian watermilfoil and other underwater plants. It may be applied in pelleted form or as a liquid. Fluridone can show good control of submersed plants where there is little water movement and an extended time for the treatment. Its use is most applicable to whole-lake or isolated bay treatments where dilution can be minimized. It is not effective for spot treatments. It may take six to twelve weeks before the dying plants fall to the sediment and decompose. When used to manage Eurasian watermilfoil, fluridone is applied several times during the summer to maintain a low, but consistent concentration in the water. Although fluridone is considered to be a non-selective herbicide, when used at low concentrations, it can be used to selectively remove Eurasian watermilfoil. Some native aquatic plants, especially pondweeds, are minimally affected by low concentrations of fluridone.

Aquatic Labeled dipotassium salt of **Endothall -** is a fast-acting non-selective contact herbicide, which destroys the vegetative part of the plant but does not kill the roots. It can be applied in a granular or liquid form. Generally endothall compounds are used primarily for short-term (one season) control of a variety of aquatic plants. However, there has been some recent research that indicates that when used in low concentrations, it can be used to selectively remove exotic weeds, leaving some native species relatively unaffected. Because it is fast acting, it can be used to treat smaller areas effectively. There is **water use restrictions** associated with the use of **dipotassium salt** of **endothall** in Washington.

Advantages

- Aquatic herbicide application can be less expensive and more effective than other aquatic plant control methods.

- Aquatic herbicides are easily applied around docks and underwater obstructions.

- 2,4-D DMA & 2,4-D BEE have been shown to be effective in controlling smaller infestations (not lake-wide) of Eurasian watermilfoil in Washington, and could also be used on the purple loosestrife and yellow flag iris.

- Washington has had some success in eradicating Eurasian watermilfoil from some smaller lakes (320 acres or less) using fluridone.

- Glyphosate is the recommended chemical for fragrant water lily control

Disadvantages

- Generally, most aquatic herbicides have use restrictions, with irrigation restrictions being the most common. Some herbicides have swimming, drinking, fishing, irrigation, and water use restrictions.

- Herbicide use may have unwanted impacts to people who use the water and to the environment.

- Non-targeted plants as well as nuisance plants may be controlled or killed by some herbicides.

- Depending on the herbicide used, it may take several days to weeks or several treatments during a growing season before the herbicide controls or kills treated plants.

- Rapid-acting herbicides may cause low oxygen conditions to develop as plants decompose. Low oxygen can cause fish kills.

- To be most effective, generally herbicides must be applied to rapidly growing plants.

- As with any pesticide, some expertise in using herbicides is necessary in order to be successful and to avoid unwanted impacts.

- Many people have strong feelings against using chemicals in water.

- Some cities or counties may have policies forbidding or discouraging the use of aquatic herbicides.

Permits

A NPDES permit is needed. Both the noxious and nuisance NPDES permits require the development of Integrated Aquatic Vegetation Management Plans (IAVMP) by the third year of control work. Monitoring of herbicide levels in the water may be required, whether the chemical has been applied directly to the water or along the shoreline where it may have gotten into the adjacent water. For emergent noxious weed control, the applicator must apply to the Washington Department of Agriculture (WSDA) for coverage under their NPDES permit each treatment season. There is no permit or application fee to obtain NPDES coverage under Agriculture's permit for Noxious Weeds.

Costs

Costs associated with chemical control of aquatic weeds will vary by site, timing and the chemical used. Generally costs will be between $200 and $1,500 per acre depending on elements included in the application, such as notifications and advertising, as well as the actual cost of the application.

MANUAL METHODS

Hand-Pulling

Hand pulling of aquatic plants is similar to pulling weeds out of a garden. It involves removing entire plants (leaves, stems, and roots) from the area of concern and disposing of them in an area away from the shoreline. In water less than three feet deep no specialized equipment is required, although a spade, trowel, or long knife may be needed if the sediment is packed or heavy. In deeper water, hand pulling is best accomplished by divers with SCUBA equipment and mesh bags for the collection of plant fragments. Some sites may not be suitable for hand pulling such as areas where deep flocculent sediments may cause a person hand pulling to sink deeply into the sediment.

Cutting

Cutting differs from hand pulling in that plants are cut and the roots are not removed. Cutting is performed by standing on a dock or on shore and throwing a cutting tool out into the water. A non-mechanical aquatic weed cutter is commercially available. Two single-sided, razor sharp stainless steel blades forming a "V" shape are connected to a handle, which is tied to a long rope. The cutter can be thrown about 20 – 30 feet into the water. As the cutter is pulled through the water, it cuts a 48-inch wide swath. Cut plants rise to the surface where they can be removed. Washington State requires that cut plants be removed from the water. The stainless steel blades that form the V are extremely sharp and great care must be taken with this implement. It should be stored in a secure area where children do not have access.

Raking
A sturdy rake makes a useful tool for removing aquatic plants. Attaching a rope to the rake allows removal of a greater area of weeds. Raking literally tears plants from the sediment, breaking some plants off and removing some roots as well. Specially designed aquatic plant rakes are available. Rakes can be equipped with floats to allow easier plant and fragment collection. The operator should pull towards the shore because a substantial amount of plant material can be collected in a short distance.

Cleanup
All of the manual control methods create plant fragments. It's important to remove all fragments from the water to prevent them from re-establishing or drifting onshore. Plants and fragments can be composted or added directly to a garden.

Advantages
- Manual methods are easy to use around docks and swimming areas.

- The equipment is inexpensive.

- Hand-pulling allows the flexibility to remove undesirable aquatic plants while leaving desirable plants.

- These methods are environmentally safe.

- Manual methods don't require expensive permits, and can be performed on aquatic noxious weeds with Hydraulic Project Approval obtained by reading and following the pamphlet *Aquatic Plants and Fish* (publication #APF-1-98) available from the Washington Department of Fish & Wildlife.

Disadvantages
- As plants re-grow or fragments re-colonize the cleared area, the treatment may need to be repeated several times each summer.

- Because these methods are labor intensive, they may not be practical for large areas or for thick weed beds.

- Even with the best containment efforts, it is difficult to collect all plant fragments, leading to re-colonization.

- Some plants, like water lilies, which have massive rhizomes, are difficult to remove by hand pulling.

- Pulling weeds and raking stirs up the sediment and make it difficult to see remaining plants. Sediment re-suspension can also increase nutrient levels in lake water.

- Hand pulling and raking impacts bottom-dwelling animals.

- The V-shaped cutting tool is extremely sharp and can be dangerous to use.

Permits

Permits are required for many types of manual projects in lakes and streams. The Washington State Department of Fish and Wildlife requires a *Hydraulic Project Approval* permit for all activities taking place in the water including hand pulling, raking, and cutting of aquatic plants.

Costs

- Hand-pulling costs up to $130 for the average waterfront lot for a hired commercial puller.
- A commercial grade weed cutter costs about $130 with accessories. A commercial rake costs about $95 to $125. A homemade weed rake costs about $85 (asphalt rake is about $75 and the rope costs 35-75 cents per foot).

Other Considerations

Does the community want to invest in weed rakes, other equipment? Manual methods must include regular scheduled surveys to determine the extent of the remaining weeds and/or the appearance of new plants after eradication has been attained.

Suitability for Lake Osoyoos

- These methods will be important after the initial herbicide application, after the chemical control methods have been evaluated for their effectiveness.

- Manual methods will also be vital in combating new infestations of Eurasian watermilfoil in subsequent years, especially around access areas.

- The currently infested areas are too large to use manual techniques as the sole source of control for Eurasian watermilfoil and most other noxious weeds. Costs would be much higher than for an integrated approach.

- Manual methods have the potential for missing Eurasian watermilfoil plants, especially after stirring up sediments.

- Manual methods have the potential for fragmentation, exacerbating the existing Eurasian watermilfoil problem.

- Cutting can be used to control small areas of fragrant water lily, especially those close to the shoreline. Using this method out in the open water would require a stable boat (not canoe) and great care not to injure oneself or another passenger. Since repeated cutting over several seasons may be required to starve the roots, this would fit best as a supplement to other control methods.

- Many landowners have already been manually removing their loosestrife for several seasons. This does not kill the mature perennial plants, but does halt seed production and can contain the infestation at current levels. If done repeatedly over several seasons it should starve the roots and kill the plants.

BOTTOM BARRIERS

Bottom Barriers and screening have been discussed extensively with landowners around the lake and have been discarded as a control option for much of the lake. Since the water levels do not fluctuate much, and due to the continual re-infestation from Canadian harvesting activities, the expense of installation and continued maintenance of Bottom Barriers is not a cost effective management tool at this time.

DIVER DREDGING

Diver dredging (suction dredging) is a method whereby SCUBA divers use hoses attached to small dredges (often dredges used by miners for mining gold from streams) to suck plant material from the sediment. The purpose of diver dredging is to remove all parts of the plant including the roots. The suction hose pumps the plant material and the sediments to the surface where they are deposited into a screened basket. The water and sediment are returned back to the water column (if the permit allows this), and only the plant material is retained. The turbid water is generally discharged to an area curtained off from the rest of the lake by a silt curtain. The plants are disposed of on shore. Diver dredging is more effective in areas where softer sediment allows easy removal of the entire plants, although water turbidity is increased with softer sediments.

According to the DOE website, "Sites suitable for diver dredging include lakes or ponds lightly to moderately infested with milfoil. Because diver dredging can be very expensive, this method is most suitable for moderate to early infestations of milfoil and for follow-up milfoil removal after an herbicide treatment. Diver hand pulling is more effective in lightly scattered patches of milfoil, whereas diver dredging may be more appropriate in denser milfoil beds. Diver dredging may also be applicable in water bodies where no herbicide use can be tolerated. Theoretically diver dredging could be used in any waterbody to eradicate milfoil; however the costs for large scale projects would become astronomical."

Diver dredging may be a suitable management method in some instances on this body of water. Those situations would typically include situations in deeper/moving water, where herbicide applications would not be effective. However, the dense infestations of Eurasian watermilfoil found in most parts of the lake make this option unfeasible at this time.

BIOLOGICAL CONTROL

Bio control agents have been historically used on Lake Osoyoos for control of Purple Loosestrife. While the agents are effective, the minor fluctuations in water level do not readily contribute to establishment of weevil populations. Ongoing and continual releases have shown some effective control.

The native Northern watermilfoil is the intended host for the milfoil weevil. However, this weevil has shown a preference for the non-native Eurasian watermilfoil. While the weevil is established in the Lake, it is not present in densities necessary to control E. milfoil.

The LOA, with assistance from DOE, has initiated a pilot project to establish rearing guidelines allowing propagation of weevils by interested parties. The pilot project consisted of purchasing the necessary equipment, tanks, aerators, etc., collecting weevils and sufficient E. milfoil to provide habitat and food source, and following the progress in the local high school science lab. The weevils, including progeny were released into the lake in 3 weeks. LOA revisited the release site to monitor any results from the re-introduction and noted a definite lowering of milfoil stems in the water column.

Grass carp have been suggested for use in milfoil control efforts, but the lack of specificity may lead to declines in native vegetation that would use nutrients in the lake, and provide competition for resources by the E. milfoil.

Advantages

- Bio control methods are long term, providing some level of control.

- The agents are inexpensive, once approved for re-distribution through APHIS, or native as in the case of the milfoil weevil.

- These methods are environmentally safe, with minimal or no effect on off target species.

Disadvantages

- Bio controls are not effective at eradication efforts,

- They take a significant amount of time to become established at densities needed to provide sufficient control.

- They are expensive to get approved through APHIS for initial release.

Permits

No permits are needed for approved bio-control releases.

Costs

- Approximately $120 to set up equipment to rear E milfoil weevils, though the collection process is very time consuming.

- At this time Purple loosestrife bio controls are distributed at no charge through a partnership with WSU Extension. But should that aspect change, bio controls are typically available for approx. $1/agent.

Suitability for Lake Osoyoos

- These methods will be important after the initial herbicide application, after the chemical control methods have been evaluated for their effectiveness.

- Bio controls will be useful in combating new infestations of Eurasian watermilfoil in subsequent years.

- The currently infested areas are too large to use bio agents as the sole source of control for Eurasian watermilfoil and other noxious weeds.

- Grass Carp are unsuitable for release in the Lake due to the lack of target specificity.

MECHANICAL

Harvesting and rototilling are options frequently used for aquatic vegetation control efforts. Both methods are used on the Canadian side of the lake to control non-native milfoil infestations.

Mechanical harvesters are large machines which both cut and collect aquatic plants. Cut plants are removed from the water by a conveyor belt system and stored on the harvester until disposal. A barge may be stationed near the harvesting site for temporary plant storage or the harvester carries the cut weeds to shore. The shore station equipment is usually a shore conveyor that mates to the harvester and lifts the cut plants into a dump truck. Harvested weeds are disposed of in landfills, used as compost, or in reclaiming spent gravel pits or similar sites.

Harvesting is usually performed in late spring, summer, and early fall when aquatic plants have reached or are close to the water's surface. Harvesters can cut and collect several acres per day depending on weed type, plant density, and storage capacity of the equipment. Harvesting speeds for typical machines range from 0.5 to 1.5 acres per hour. Depending on the equipment used, the plants are cut from five to ten feet below the water's surface in a swath 6 to 20 feet wide. Some modern harvesters can cut plants in a range of water depths. Because of machine size and high costs, harvesting is most efficient in lakes larger than a few acres. Harvesting can be an excellent way to create open areas of water for recreation and fishing access.

Along with plants, harvesters also collect a large number of small fish and invertebrates. Amphibians and turtles have been known to be collected as well.

Advantages

- Harvesting results in immediate open areas of water.
- Removing plants from the water removes the plant nutrients, such as nitrogen and phosphorus, from the system.
- Harvesting as aquatic plants are dying back for the winter can remove organic material and help slow the sedimentation rate in a waterbody.
- Since the lower part of the plant remains after harvest, habitat for fish and other organisms is not eliminated.
- Harvesting can be targeted to specific locations, protecting designated conservancy areas from treatment.

Disadvantages

- Harvesting is similar to mowing a lawn; the plant grows back and may need to be harvested several times during the growing season.
- There is little or no reduction in plant density with mechanical harvesting.
- Off-loading sites and disposal areas for cut plants must be available. On heavily developed shorelines, suitable off-loading sites may be few and require long trips by the harvester.
- Some large harvesters are not easily maneuverable in shallow water or around docks or other obstructions.
- Significant numbers of small fish, invertebrates, and amphibians are often collected and killed by the harvester.
- Harvesting creates plant fragments which may increase the spread of invasive plant species such as Eurasian watermilfoil throughout the waterbody.
- Although harvesters collect plants as they are cut, not all plant fragments or plants may be picked up. These may accumulate and decompose on shore, often forming new infestations.
- Harvesters are expensive and require routine maintenance.
- Harvesting may not be suitable for lakes with many bottom obstructions (stumps, logs) or for very shallow lakes (3-5 feet of water) with loose organic sediments.

- Harvesters brought into the waterbody from other locations need to be thoroughly cleaned and inspected before being allowed to launch. Otherwise new exotic species could be introduced to the waterbody.

Permits

Harvesting in Washington requires hydraulic approval from the Department of Fish and Wildlife. Some Shoreline Master Programs may also require permits for harvesting, but in Okanogan County that is not the case. Because harvesting collects fish along with aquatic plants, some additional monitoring may be required when harvesting in salmon bearing waters.

Costs

Costs per acre vary with numbers of acres harvested, accessibility of disposal sites to the harvested areas, density and species of the harvested plants, and whether a private contractor or public entity does the work. Private contractors generally charge $500 to $800 per acre. The purchase price of harvesters ranges from $35,000 to $110,000. There are several harvester manufacturers in the United States and some lake groups may choose to operate and purchase their own machinery rather than contracting for these services.

Rotovation:

A rotovator is a barge-mounted rototilling machine that lowers a tiller head about eight to ten inches into the sediment to dislodge milfoil root crowns. The mechanical agitation produced by the tiller blades dislodges the root crowns from the sediment and the buoyant root masses float to the water surface. Since the entire plant is removed, plant biomass remains reduced in the treatment area throughout the growing season and often longer. Rotovation often provides two full seasons of control (Gibbons et. al, 1987). Unlike harvesters, rotovators do not have the capability to collect the plants.

Rotovation is a way to mechanically remove milfoil to provide open areas of water for recreational activities and navigation. Waterbodies suitable for rotovation include larger lakes or rivers with widespread, well-established milfoil populations where milfoil eradication is not an option. Since on-going rotovation programs are very expensive, having a large lake population or a motivated local government to share these costs is crucial. Because rotovation is expensive and multiple permits are needed, rotovation has not become a wide-spread milfoil control activity in Washington or elsewhere in the United States.

Rotovation is not recommended in water bodies with early infestations of milfoil since fragments are created and rotovation may increase the spread of milfoil throughout the waterbody. Because rotovation creates turbidity, rotovation may not be appropriate in salmon-bearing waters, although sometimes Fish and Wildlife staff are able to provide windows of time when rotovation activities will have the least impact on fish. Because rotovation and the resultant turbidity may impact the entire waterbody, it should be conducted under the direction of an integrated aquatic vegetation management plan.
Rotovation requires a Hydraulic Project Approval from Fish and Wildlife.

Factors to consider when designing a rotovation program include:
•Waterbody surface area, width, and depth.
•Vegetated acres.
•Bottom contours and bottom obstructions such as stumps, rocks, and other debris.
•Traffic patterns.
•Prevailing winds.
•Rotovator launching and off-loading sites.
•Sediment type.

•Shoreline development.
•Sensitive areas (critical habitat).

A waterbody committee and/or local government staff should identify acreages and areas to be rotovated. Priorities may be determined by who funds the program. A local government will be more interested in rotovating public areas, whereas local residents may be interested in rotovating areas in front their homes. However, generally high use areas such as public parks, community access points, navigation channels, public boat launches, and water ski lanes receive priority. Sometimes rotovators can be used to create fishing lanes in dense beds of milfoil to provide better fishing access to anglers.

Prior to rotovation, machinery launch sites (a paved ramp with deep water is best) need to be identified. Since rotovators do not collect plants as they work, a method for removing plants from the water should be developed. This may involve having a harvesting machine follow behind the rotovator to collect plants or hiring people to rake plants off beaches. Rotovation activities should begin at the farthest point up stream. The plants are then carried downstream and get caught up on the remaining dense milfoil beds.

During a rotovation project, the rotovator tilling head is lowered into the sediment and power is applied. The rotating head churns into the sediment dislodging milfoil root crowns and plants, and a plume of sediments. The rotovated plants eventually sink or wash up on shore and the sediments gradually settle from the water. Canadian plant managers have recorded milfoil stem density and root crown reductions of better than 99 percent after rotovation test trials (British Columbia Ministry of Environment memo dated 1991). Where repeated treatments have occurred at the same site over several consecutive years, treatment intervals may extend longer than two years (Gibbons, et. al, 1987).

In a few waterbodies such as in the Pend Oreille River, rotovation may be performed year-round. In most water bodies, timing is dependent on fish windows. Washington Fish and Wildlife does not want rotovation activities to take place when fish are spawning or juvenile salmon are migrating through the waterbody.

For efficacy of milfoil removal, it's best to begin operations in early spring and resume again in the fall. Rotovation is less effective in the summer when the long milfoil plants wrap around the rotovating head, slowing down the operation. If rotovation is done during the summer, it is more efficient to cut or harvest the plants beforehand. Weather creates winter rotovation delays, although it is possible to rotovate throughout the winter months (as long as the waterbody doesn't freeze). Delays in the rotovation schedule can result from high winds, thunderstorms, freezing water, and mechanical failure. There is a lot of maintenance and some down time on machinery working on the water.

Complaints about rotovation include increased plant fragments washing up along shorelines, broken water intakes, it is important to establish some clear guidelines and policies to help make decisions and to settle disputes.

General impacts of rotovation:

- Rotovators stir sediments into the water column. In addition to the sediments, buried toxic materials and/or nutrients may be released.

- Generally turbidity is short-term and the water returns to normal within 24 hours, but the length of time that sediments remain suspended depends on sediment type.

- Plants and root crowns are uprooted from the sediment and unless a plant removal plan is in place, these plants will either sink or be washed on shore.

- Rotovation appears to stimulate the growth of native aquatic plants. Whether this is due to the removal of milfoil, the action of the rotovator stimulating seed or propagule germination, or a combination of these factors is not known.

- Rotovators are also large machines with hydraulic systems and fuel that occasionally leaks or is spilled. The operator should have a spill plan and containment equipment on board for emergency use.

In 1987, Ecology conducted an evaluation of rotovation in Lake Osoyoos. This lake was chosen because it has a history of mining and agricultural use and therefore might represent a “worst case” scenario in terms of the potential for release of contaminants from sediment. The objectives of the study were to document effectiveness of rotovation by measuring changes in milfoil stem densities before and after treatment, and to assess impacts of rotovation on selected water quality parameters, benthic invertebrates, and the fisheries. Although the rotovator malfunctioned during the test (the hydraulic system driving the rototiller was not functioning properly), the results were consistent with data collected by the British Columbia Ministry of the Environment of sites rotovated by a fully operating rotovator. During the Lake Osoyoos rotovator test, rotovation appeared to have little impact on fish, water quality, or benthic invertebrates. However during this test, milfoil stem densities were not reduced to the extent that should have occurred had the machinery been operating properly. Although the results indicated only short-term impacts associated with rotovation, the test was faulty and it is difficult to draw firm conclusions. This study was not repeated.

CONCLUSION

Lake Osoyoos covers an international border and is home to a variety of fish, birds, and other wildlife. It offers a vast array of activities, such as fishing, boating and swimming. A variety of interests will drive the Integrated Aquatic Vegetation Management Plan. No one control method will work for every aspect of the lake. Therefore we will use a truly integrated approach based upon the individual shore owners' needs and the needs of the lake at individual sites.

Many landowners have already begun chemical treatments to reduce the Eurasian watermilfoil infestations along their shore area. These activities have been performed by licensed applicators using the aquatic labeled herbicides available in Washington State. Restrictions were originally placed on the Permit, disallowing herbicide use within a quarter mile of the international border. These restrictions remain in place at this time, and applications are limited to 10 acres. The Noxious Weed Board will work to increase the acreage limitations based on needs by lake shore residents.

Others will continue to experiment with weevil rearing and attempt to improve upon the collection process. In 2013, WSU Extension Douglas County assisted in the collection of debris from the shoreline to determine if that was a viable collection process. Weevils were found in the debris, but not in sufficient quantities to make it effective. The collection process will be attempted again in 2014, trying different timing windows and distance from water. The tanks and equipment provided through the DOE planning grant have been made available to the Oroville High School, OCNWCB, and interested residents, to both propagate additional weevils and use as an educational tool.

Raking of milfoil and removal of debris from along the shore will be sufficient in some areas. This has been the preferred method for many landowners with limited infestations. The ease of constructing a rake or hoe to collect milfoil, the limited expense, and availability of rakes and hoes, has increased its popularity. Landowners who prefer to rake and remove debris from the lake will be encouraged to allow the debris to rest on the shoreline for several days to allow weevil migration back to the water.

Talks will continue with Canada to explore the possibility of utilizing their harvester south of the border. While the harvester will not effectively control the aquatic vegetation, it will allow for safer recreation.

While the main emphasis of control efforts will change from landowner to landowner, the objective of all lake owners is to reduce infestations of Eurasian watermilfoil and other aquatic noxious weeds to a level that is tolerable, promotes an increase functionality of habitat for fish and aquatic organisms, and provides a safe environment for recreation and other uses of the lake.

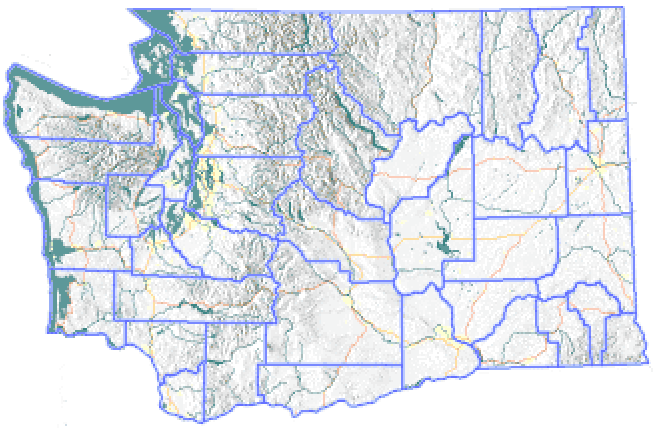
Table 1:

PLANT SPECIES AS PER DOE SURVEYS

Scientific name	Common name
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Equisetum sp.	horse tail
Heteranthera dubia	water star-grass
Iris pseudacorus	yellow flag
Juncus sp. or Eleocharis sp.	small grass-like plants
Lythrum salicaria	purple loosestrife
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum spicatum	Eurasian water-milfoil
Najas flexilis	common naiad
Nymphaea odorata	fragrant waterlily
Phalaris arundinacia	reed canarygrass
Potamogeton crispus	curly leaf pondweed
Potamogeton foliosus	leafy pondweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton natans	floating leaf pondweed
Potamogeton nodosus	longleaf pondweed
Potamogeton richardsonii	Richardson's pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton zosteriformis	eel-grass pondweed
Ranunculus aquatilis	water-buttercup
Ranunculus flammula	creeping buttercup
Sagittaria sp.	arrowhead
Schoenoplectus acutus	hardstem bulrush
Schoenoplectus sp.	naked-stemmed bulrush
Schoenoplectus tabernaemontani	softstem bulrush
Solanum sp.	nightshade
Stuckenia pectinata	sago pondweed
Stuckenia sp.	pondweed
Typha latifolia	common cat-tail
Utricularia sp.	bladderwort
Vallisneria americana	water celery
Zannichellia palustris	horned pondweed

Osoyoos Lake

County	Okanogan
Latitude	48.95
Longitude	119.4283
Ecoregion	Columbia Basin
years surveyed	2012, 2011, 2010, 2009, 2005, 1993
map link	



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Typha latifolia	common cat-tail
Utricularia sp.	bladderwort
Vallisneria americana	water celery
Zannichellia palustris	horned pondweed

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Carex sp.	8/17/2005	1	Ecology	
Ceratophyllum demersum	8/17/2005	1	"	
"	7/3/2012		"	did not inventory whole lake
Chara sp.	8/17/2005	2	"	
"	10/10/2009		Ecology, Osoyoos Lake Association	no distribution values, did not inventory entire area, late in season.
"	7/3/2012		Ecology	
Eleocharis sp.	8/17/2005	2	"	submersed species
Elodea canadensis	8/17/2005	1	"	
"	7/3/2012		"	
Equisetum sp.	8/17/2005	1	"	shoreline
Heteranthera dubia	8/17/2005	2	"	
Iris pseudacorus	8/17/2005	2	"	almost entirely in southern outlet area
"	10/10/2009		Ecology, Osoyoos Lake Association	mostly growing in area south of state park

Juncus sp. or Eleocharis sp.	10/10/2009		"	shallow water
Lythrum salicaria	8/17/2005	2	Ecology	
Myriophyllum sibiricum	7/3/2010	1	Ecology, Osoyoos Lake Association	
"	7/3/2012		Ecology	
Myriophyllum spicatum	1/1/1993		"	reported
"	8/17/2005	3	"	scattered in all areas of lake, but rarely dominant
"	10/10/2009		Ecology, Osoyoos Lake Association	scattered patches, not at the surface
"	7/3/2010	3	"	spotty growth, but some dense patches
"	9/20/2011		Ecology, Okanogan NWCB	
"	7/3/2012		Ecology	some looks like it may be a hybrid
Najas flexilis	8/17/2005	3	"	large dense patches, especially along east side of lake
Nymphaea odorata	8/17/2005	3	"	white flowered variety. Found only in southern outlet area, south of park boat launch. Growing in scattered small to medium sized patches along shore.
"	10/10/2009		Ecology, Osoyoos Lake Association	where lake narrows and river begins at south end, dense in this region
"	9/20/2011		Ecology, Okanogan NWCB	
Phalaris arundinacia	8/17/2005	2	Ecology	
Potamogeton crispus	8/17/2005	1	"	east side, with turions in leaf axils, growing with H. dubia
"	7/3/2010	2	Ecology, Osoyoos Lake Association	
"	7/3/2012		Ecology	
Potamogeton foliosus	8/17/2005	2	"	with achenes
Potamogeton gramineus	8/17/2005	2	"	
Potamogeton illinoensis	8/17/2005	2	"	in southern outlet area
"	7/3/2010	1	Ecology, Osoyoos Lake Association	
Potamogeton natans	8/17/2005	3	Ecology	

"	10/10/2009		Ecology, Osoyoos Lake Association	
"	7/3/2012		Ecology	
Potamogeton nodosus	8/17/2005	3	"	
"	10/10/2009		Ecology, Osoyoos Lake Association	
"	7/3/2010	3	"	
Potamogeton richardsonii	8/17/2005	2	Ecology	
"	10/10/2009		Ecology, Osoyoos Lake Association	
"	7/3/2010	2	"	
"	9/20/2011		Ecology, Okanogan NWCB	
"	7/3/2012		Ecology	
Potamogeton sp (thin leaved)	7/3/2010	2	Ecology, Osoyoos Lake Association	
"	7/3/2012		Ecology	
Potamogeton zosteriformis	7/3/2012		"	
Ranunculus aquatilis	8/17/2005	2	"	white petals, no floating leaves
"	7/3/2010	1	Ecology, Osoyoos Lake Association	
"	7/3/2012		Ecology	blooming
Ranunculus flammula	8/17/2005	1	"	seen in one location, likely more
Sagittaria sp.	8/17/2005	1	"	submersed, underwater leaves only, southern outlet area
Schoenoplectus acutus	8/17/2005	2	"	
"	10/10/2009		Ecology, Osoyoos Lake Association	
Schoenoplectus sp.	7/3/2010	2	"	
Schoenoplectus tabernaemontani	8/17/2005	2	Ecology	
Solanum sp.	8/17/2005	2	"	
Stuckenia pectinata	8/17/2005	2	"	
"	10/10/2009		Ecology, Osoyoos Lake Association	

"	7/3/2010	2	"	
Stuckenia sp.	8/17/2005	1	Ecology	long leaves, no achenes
"	10/10/2009		Ecology, Osoyoos Lake Association	different species from S. pectinata
Typha latifolia	8/17/2005	2	Ecology	
"	10/10/2009		Ecology, Osoyoos Lake Association	
Utricularia sp.	8/17/2005	2	Ecology	probably U. vulgaris. In protected areas of southern outlet
Vallisneria americana	8/17/2005	2	"	
Zannichellia palustris	8/17/2005	1	"	floating fragment seen
"	7/3/2010	1	Ecology, Osoyoos Lake Association	

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
2. "Source" is the organization that provided the data. "Ecology" refers to the Washington State Department of Ecology.

Washington State Department of Ecology

Questions or comments may be sent to Jenifer Parsons, Environmental Assessment Program, Central Regional Office.

Pearrygin Lake State Park Management Plan

Washington State Parks Centennial 2013 Vision

In 2013, Washington's state parks will be premier destinations of uncommon quality, including state and regionally significant natural, cultural, historical and recreational resources that are outstanding for the experience, health, enjoyment and learning of all people.

Washington State Parks Mission

The Washington State Parks and Recreation Commission acquires, operates, enhances, and protects a diverse system of recreational, cultural, and natural sites. The Commission fosters outdoor recreation and education statewide to provide enjoyment and enrichment for all and a valued legacy to future generations.

WASHINGTON STATE
PARKS AND RECREATION COMMISSION

CAMP
Washington State Parks
Classification and Management Planning Project

ACKNOWLEDGMENTS AND CONTACTS

The Washington State Parks and Recreation Commission gratefully acknowledges the many stakeholders and the staff of Pearrygin Lake State Park who participated in public workshops, reviewed voluminous materials, and because of it, made this a better plan.

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Commissioners and Director (at time of land classification adoption):

Clyde Anderson
Mickey Fearn
Bob Petersen
Eliot Scull
Joe Taller
Joan Thomas
Cecilia Vogt
Rex Derr, Director

PEARRYGIN LAKE STATE PARK LAND CLASSES, RESOURCE ISSUES AND MANAGEMENT APPROACHES

CERTIFICATE OF ADOPTION

The signatures below certify the adoption of this document by Washington State Parks for the continued management of Pearrygin Lake State Park.

Signatures on file

Rick Lewis, Park Manager	Date
Dave Jaquish, Assistant Region Manager (Park supervisor)	Date
Jim Harris, Region Manager	Date
Judy Johnson, Deputy Director	Date

Table of Contents

PREFACE

The Washington State Parks and Recreation Commission (Commission) manages a diverse array of 120 parks located throughout the state.

The Commission adopted the Centennial 2013 Plan in October, 2003, thereby creating a focus intended to energize and bring together the agency, state leadership and the public, to work toward a parks system all can celebrate as it turns 100 years old and prepares for a second century of service. The Centennial 2013 Plan blends public and private funding, engages more partnerships and creates greater public ownership of the system.

In November 2005, the Commission adopted the Centennial 2013 Legacy Priorities. Pearrygin Lake State Park was chosen as one of six parks that would be suitable for significant investment to provide for new recreation opportunities and major upgrades at the existing park. The designation and previous Commission interest in the state park led to a public process that has led to this plan and a step closer to achieving an important goal for the Centennial 2013 Plan that reads, “All 120 parks have land-use plans supported by the public and Commission (which includes the direction of care of historic buildings and sites and natural resources).”

These land-use plans follow a process that has been used by the Commission since 1996, called the CAMP Project. CAMP is an acronym for Classification and Management Plan. The modifications from CAMP to land-use plans allow for a simplified and efficient process that can be used by a wider number of staff to complete all 120 plans by 2013.

The important elements of the CAMP project are retained. One of the most important elements is the classification of lands. In 1995, the Commission adopted a land classification system. Application of the system creates zones, or land classifications, within a park (see Appendix A.) Six distinct classifications determine what recreational uses and types of developments are appropriate in different areas of a park. In general, sensitive areas are classified restrictively and allow only low-intensity uses and development of minor facilities. Less sensitive areas are classified to allow higher-intensity uses and more extensive facilities development.

A CAMP brings together the customers, nearby community, stakeholders and State Parks staff in a public process that forges a common vision of what the state park should become (see Appendix B: CAMP Project Planning Principles). Through a public process that we believe to be as open as any, staff and public participants identify resource management issues, look at alternative approaches for addressing them. The outcome is this plan that will help focus all our efforts to balance resource protection with recreational opportunities in a park. For State Parks’ staff, this document represents policy approval and a means to create a state park that meets the Centennial 2013 Vision:

In 2013, Washington's state parks will be premier destinations of uncommon quality, including state and regionally significant natural, cultural, historical and recreational resources that are outstanding for the experience, health, enjoyment and learning of all people.

SUMMARY

Pearrygin Lake State Park provides a wide-range of outdoor recreational pursuits, while preserving valued natural and cultural resources. This plan will describe the park land classification, long-term boundary and prescribe management objectives.

PURPOSE

The purpose of this document is to: 1) orient readers to the park and the agency's park management planning system, 2) identify park natural, cultural, and recreation/facility management issues, and 3) provide initial direction to park staff (suggested management approaches) to address these issues. The ultimate purpose of this document is to describe how the agency intends to balance recreational use with measures to protect natural and cultural resources.

This document is divided into five sections, with several appendices:

Section 1: Provides a brief overview of the park including its geography, historical background, major attributes, and public use.

Section 2: Describes the public process that led to the CAMP.

Section 3: Outlines management objectives established for the park.

Section 4: Describes the park's land classifications (management zoning) and long-term park boundary

Section 5: Lists natural, cultural, and recreational/facility resource issues identified through the public planning and outlines general approaches toward resolving them.

Section 6: Other Park Plans

Appendices contain additional supporting documentation pertinent to this plan.

SECTION 1: PARK DESCRIPTION

PEARRYGIN LAKE STATE PARK - RECREATION AREA

Location: Pearrygin Lake State Park is located 4 miles north of Winthrop in the Upper Methow Valley and is accessed off of the East Chewuch and Bear Creek Roads which are on the northeast side of State Highway 20.

Acreage: 962.76 acres with 16,783.57 feet freshwater shoreline.

Lands inventory as of plan adoption:

Park Name	Grantor / Grantee	Status	Date	Exp. Date		Acre	Fresh	Salt
L-01	RAINIER TELEPHONE CO	A	3/25/1974	3/24/2004				
L-02	COURT, ASHLEY & LINDA	A	5/22/1998					
			SUBTOTAL					
P-1	HEATON, PAUL & MARTHA		5/21/1959			500.00	5,300.00	0.00
P-1A	PAUL HEATON		6/15/1959			0.00	0.00	0.00
P-2	US BUREAU OF LAND MGMT		3/25/1964			78.17	2,900.00	0.00
P-3	WA DEPT OF FISH & WILDLIFE		11/ 6/1959			1.70	0.00	0.00
P-4	COURT, ASHLEY & LINDA		5/22/1998			25.00	0.00	0.00
P-5	HINMAN, JEAN LLOYD		5/22/2000			0.23	0.00	0.00
P-6	LOTT, DERRY L. & LORNA R.		3/17/2004			6.33	144.73	0.00
P-7	HINMAN, JEAN LLOYD		8/31/2004			65.00	1,170.80	0.00
P-8	BACKROADS LLC (LOTT)		10/ 1/2004			23.00	1,868.04	0.00
P-9	MARBLE, CURT & SUZANNE		8/ 1/2005			22.48	1,200.00	0.00
P-10	YOCKEY FAMILY LIMITED		11/29/2005			57.63	0.00	0.00
P-11	YOCKEY FAMILY LMT		7/18/2006			64.60	1,800.00	0.00
P-12	TRUST FOR PUBLIC LANDS		7/18/2006	7/18/2008		118.62	2,400.00	0.00
			SUBTOTAL			962.76	16,783.57	0.00
R-1	HINMAN, JEAN LLOYD		5/22/2000		$0.00	-0.77	0.00	0.00
			SUBTOTAL		$0.00	-0.77	0.00	0.00
			PARK TOTAL		**$6,683,572.74**	**961.99**	**16,783.57**	**0.00**
			REPORT TOTAL		**$6,683,572.74**	**961.99**	**16,783.57**	**0.00**

Historical Background: The Methow Valley was first opened to the white man by fur trappers and traders in the early 1800s and later became an access route into the large mining region in the upper Skagit drainage. The town of Winthrop was founded in 1894 by Boston-bred and Harvard-educated Guy Waring as a trading post handling supplies needed by the mining operations as well as those for the homesteaders who were gradually moving into the area. Much of the acreage now included in the park was settled by just such homesteaders who became the mainstay of valley life when the mining boom came to an end in the early 1900s.

Facilities: 74 utility sites and 93 standard sites; 2 group camps with 16 tent sites, vault toilet, water, and parking facilities; 2 primitive sites w/o vehicle access; 6 comfort stations, 45 picnic sites, two boat launches, 3.5 miles of roadway, 2 contact station, 3 residences, park shop, storage building, 2 irrigation pumphouse, bathhouse, 2 trailer dump, boat handling floats, and an ADA accessible fishing pier.

Activities: Fishing, boating, swimming, hiking, picnicking, camping, cross country skiing, sledding and snowmobiling.

Attendance:

Year	Utility	Other	Day Use	Total
2000	15,662	22,483	193,429	231,574
2001	15,134	19,823	155,650	190,607
2002	15,095	20,693	114,799	150,587
2003	15,177	20,031	123,592	158,800
2004	15,434	19,604	174,587	209,925

OPERATIONS:

Interpretation: Junior Ranger Program, Tuesday night Fly Fishing Demonstration and Thursday evening with the Ranger (6/15-Labor Day), Trees are Terrific with the Methow Valley 5th grade annually.

Staffing:

Position	Staff Months
Ranger 4	12.00
Ranger 3	12.00
Ranger 1	12.00
Senior Park Aide	12.00
Const/Maint. Project Specialist 1	12.00

Seasonal Park Aide (6) 25.30

PEARRYGIN LAKE STATE PARK - RECREATION AREA (continued)

Changes In Last Biennium To...

Park Structures/Utility System

- Building #2, Bathhouse – New sewer lines, interior remodel, and floors tiled
- Installation of Chlorinator mixing tanks

Use Of Park By Public

- One of the top state parks for camping and with the additional acquisitions the park has potential for additional summer and winter trail use.

Methods Of Operation

Park on Central Reservation System.

Major Accomplishments in Last Two Years...

- Completion of the CAMP process
- Major acquisitions
- Development of stores
- New comfort station
- Electrification of camping loop A
- Construction of ADA accessible picnic site
- Construction of outdoor projection screen(community partnership)
- Replace lighting in comfort station #2(deferred maintenance)
- Campground redevelopment at new property (volunteer and regional work party)

Figure 1. Pearrgyin Lake State Park vicinity map

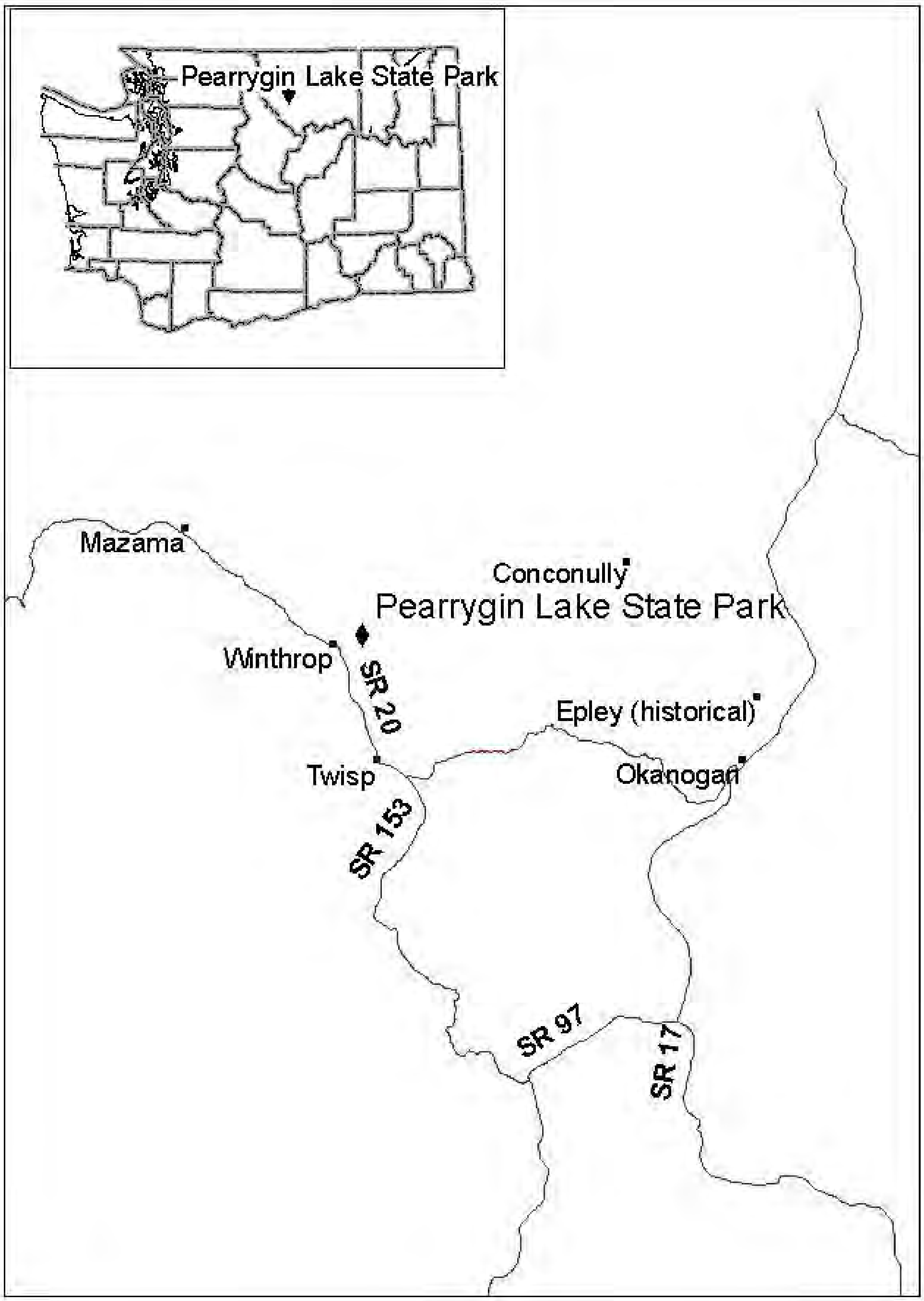


Table 1. Summary of Pearrgyin Lake State Park Issues

Natural Resource Issues	♦ Fire prevention preparedness ♦ Improvement of water quality ♦ Inventory of natural plant and animal communities ♦ Land Classification ♦ Maintenance of existing vegetation in the campgrounds ♦ Planting grass, trees and shrubs at the west developed area ♦ Protection of aquatic plant and animal communities ♦ Protection of natural plant and animal communities ♦ Sustainability in the new area development ♦ Weed management of the new and existing properties ♦ Wildlife viewing and environmental interpretive opportunities
Cultural Resource Issues	♦ Identification and protection of Native American archaeological and cultural resources ♦ Interpretation of Methow Valley history
Recreational Resource Issues	♦ Access of water-front campsites to lake ♦ Acquisition plan for protection of the Bear Creek corridor to Davis Lake ♦ Adding more cabins and yurts ♦ Affect of land acquisition on county and local government ♦ Balance of issues from the various public groups ♦ Better and more showers ♦ Better enforcement of State Parks rules, including quiet hours ♦ Boat management on the lake ♦ Choosing to improve Pearrygin Lake State Park over other state parks ♦ Connecting the state park to other trails ♦ Connecting the state park to Winthrop ♦ Contribution of the state park to the community ♦ Control the hornets ♦ Cooperative management with the Washington Department of Fish and Wildlife (WDFW) ♦ Create a design standard for the state park ♦ Creating access points to new state parks property ♦ Creation of a construction budget and timeline ♦ Developing moorage on the lake ♦ Development of a single entrance road ♦ Dry storage of boats ♦ Eliminate the parking fee ♦ Events at the state park ♦ Fishing on the lake, including fishing docks ♦ Foundation or Friends of Pearrygin State Park group to collect donations to help improve facilities ♦ Four season park open to public ♦ Golf Course management and development ♦ Improvement of the central reservations system ♦ Improvement of utilities and facilities at the existing campsites ♦ Increase privacy around campsites

	♦ Increase the number of waste receptacles or move them to be more convenient ♦ Lake level affect on recreation ♦ Location and number of boat launches ♦ Location, number and configuration of swimming areas ♦ Location, services and development of the store ♦ More full or partial hookup campsites with some campsites along the lake ♦ Noise reduction in the state park ♦ Number, location and type of campsites and cabins ♦ Off-leash area for dogs ♦ Okanogan County zoning change ♦ Operation of the go-kart track ♦ Outdoor covered area for washing dishes ♦ Pet waste control ♦ Proper staffing of the state park ♦ Provide an outdoor stage for movies and other programming ♦ Reduce conflict between trail users ♦ Reduce light pollution from the state park ♦ Retaining the qualities of Pearrygin Lake State Park while incorporating the new properties ♦ Should State Parks and the Washington ♦ Department of Fish and Wildlife (WDFW), make boundary line adjustments to differentiate management areas? ♦ Shuttle connecting state park to Winthrop ♦ Signage in the state park, particularly when the campgrounds are physically separated ♦ Tent-only campsites that are separate from RVs ♦ Trail management and development in the state park ♦ Upgrading and location of facilities at the west developed area ♦ View shed protection between the state park and East Chewuch Rd. ♦ What will happen to the Fowler Road? ♦ Website information on the state park and facilities ♦ Wireless Internet or cable at the state park

SECTION 2: PARK PLANNING PROCESS

The planning process began with a series of public workshops and ended when the Commission provided its policy direction. The planning team gathered public comment at several community workshops. The workshops were designed to be open-ended forums to allow the public to actively participate in the future plans for Pearrygin Lake State Park.

The planning team took all concerns into consideration and responded to any issues that arose during the planning process. The process will lead to a "blueprint" stage where the park programs and facilities are renewed and expanded. The planning team is confident that the Pearrygin Lake State Park CAMP may be implemented, because it represents a common vision with many in the community and amongst our customers.

Figure 1 Public Workshop, October 13, 2005

Stage 1. Identify hopes and concerns of the community and park customers

To gather hopes and concerns, the planning team held a public workshop on Oct. 13, 2005, at the Liberty Bell High School between Twisp and Winthrop. The team sent invitations to a mailing list of several hundred people, including nearby landowners. The Methow Valley News published information about the workshop. The team also sent more than 3,000 e-mails to customers of Pearrygin Lake State Park and others and invited people to tell the planning team what hopes and concerns the plan should address. Responses from customers and workshop attendees were posted on State Parks' planning Webpage.

Stage 2. Explore alternative approaches to address community and customer issues

*In res*ponse to the community and customer comments in the first stage, the planning team developed alternative approaches that might meet peoples' needs. In order to gather comments on the alternatives, the team sent a notice to a larger mailing list inviting people to a second workshop and offered to send them the alternatives. The list grew as people expressed interest and was over 700 people at that time. The Methow Valley News, The Wenatchee World and local radio stations helped broaden outreach by publishing articles and making announcements. A second workshop took place on Jan. 11, 2006, at the Liberty Bell High School. The planning team took comments at the workshop and asked for final comments by January 23.

Figure 2: Public Meeting January 11, 2006

Stage 3. Prepare preliminary recommendations to address issues

The planning team considered the comments received to date and developed preliminary staff recommendations based on the best available information. Staff shared its preliminary recommendations with the public at a third workshop on March 23.

Stage 4. Propose final recommendations for formal agency and Commission adoption

After hearing from the public, the planning team made its final recommendations to the Commission. The Commission meeting was open to the public and occurred in Chelan on August 24, 2006. The public testified concerning the final staff recommendations, and if they could not be present for the meeting, there was a procedure to provide written comments to the Commission.

The Commission approved the land classification scheme, the park long-term boundary and the facilities concept plan. Following Commission approval, staff finalized this document. The CAMP captures the main issues and suggests management approaches to address them. This document has undergone extensive staff review and sign-off process prior to being accepted by the agency Deputy Director.

In the future, park and region staff, through open houses and other public forums, will solicit stakeholder comments on the progress made towards addressing the issues presented herein and to assist staff in the identification of new emerging issues. The intent is to keep this document viable and up-to-date with changing and emerging issues that affect park management.

SECTION 3: PARK OBJECTIVES

During initial stages of planning, staff worked with stakeholders to craft a series of objectives to guide future management of the park. Management objectives are outlined in table 2, below.

Table 2: Park Objectives.

Relationship to Adjacent Property Owners and the Community:

- Recognize the park's importance in the economic and social life of the community and actively participate in community economic development and other programs.
- Be aware of the potential positive and/or negative impacts on adjacent property owners of continued park development and management.

Recreation:

- Provide access to Pearrygin Lake State Park for a variety of water-based activities.
- Develop a variety of year-round trails and trail-related recreation opportunities, focused on hiking, biking, equestrian, cross-country skiing (groomed and non-groomed), but also provide when not in conflict with the primary uses, opportunities for mushing, sledding, tubing and other under served winter recreational activities.
- Offer affordable summer and winter overnight campsites and cabins.

Financial Strategy:

- Make the state park a model of self-sufficiency so that it can provide public services that heighten the visitor's park experience and is complementary to community enterprise and minimally impacts park natural, recreational and cultural landscapes.
- Develop programs and facilities that will encourage camping customers to stay longer.
- Seek partners that will help create the facilities and provide the services requested by the community and state park customers.

Natural Resources:

- Inventory, protect, preserve, and interpret natural resources of the park, including rare, fragile and/or high quality examples of vegetative communities, associations and species; important fish and wildlife corridors and habitat areas.
- Preserve natural resources by developing a sustainable park that uses renewable resources when possible.
- Use integrated pest management practices to control noxious weeds and other pests in the park area.
- Emphasize, to the extent possible, native plants consistent with a sustainable landscape and wildlife habitat enhancement.

Cultural Resources:

- Inventory, protect, preserve, and appropriately interpret the key cultural resources of the park.

(Continued on other side)

Pearrygin Lake State Park Management Objectives (Continued)

Park Boundary:

- Participate in the land conservation effort with other community groups to protect the natural view of the Pearrygin Lake Basin for our park visitors so that people recreating there may have a quality experience.
- Identify a long-term boundary and property management plan that establishes priorities for land acquisition, surplus, easements, and a variety of cooperative management approaches with nearby resource managers and park neighbors so that park visitors may have a quality experience.

Park Facilities:

- Draft an achievable plan for ongoing maintenance of the existing park facilities and development and maintenance of the proposed facilities.
- Create a park facility that is compatible with the site and community and establishes high standards for facilities, programs and customer service.

Customer Service

- Provide appropriate staffing so that customers are satisfied with the level of agency and concessionaire service.

March 30, 2006

SECTION 4: LONG-TERM BOUNDARY AND PARK LAND CLASSIFICATIONS

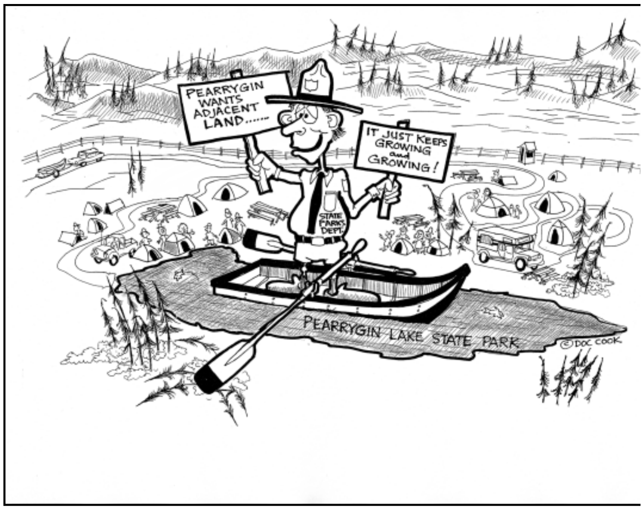


Figure 3: Cartoon by DOC Cook, Methow Valley News, January 11, 2006. Used with permission.

<u>Long-Term Boundary</u>

How big Pearrygin Lake State Park should be was an important issue for the community. It turned out to be one of the most hotly discussed topics at the workshops and in the local paper.

Staff began the process by considering land acquisitions that were approved by the Commission. Those purchases included the Yockey Property on the west side of Pearrygin Lake State Park and the Court property south of Pearrygin Lake State Park.

Staff next used mapping technology to approximate the view area based on a line that went down the middle of Pearrygin Lake south through the Court property.

Staff felt it was important to ensure that landowners affected by the possible long-term boundary were notified, and individual letters were sent to them.

The planning team looked at several alternatives, including a *long-term* boundary only as large as the existing state park and the property acquisitions already in progress. The team proposed a *long-term* boundary defined by Bear Creek Road on the north, south and east, and on the west, by a line approximating the “military crest” of Studhorse Mountain. A two hundred foot corridor from the East Chewuch Road to the Pearrygin Lake State Park entrance is included to enhance the visitor experience as they approach the state park. The *long-term* boundary does not extend south of the Bear Creek Road, because of recent conservation easements that adequately protect the land view area.

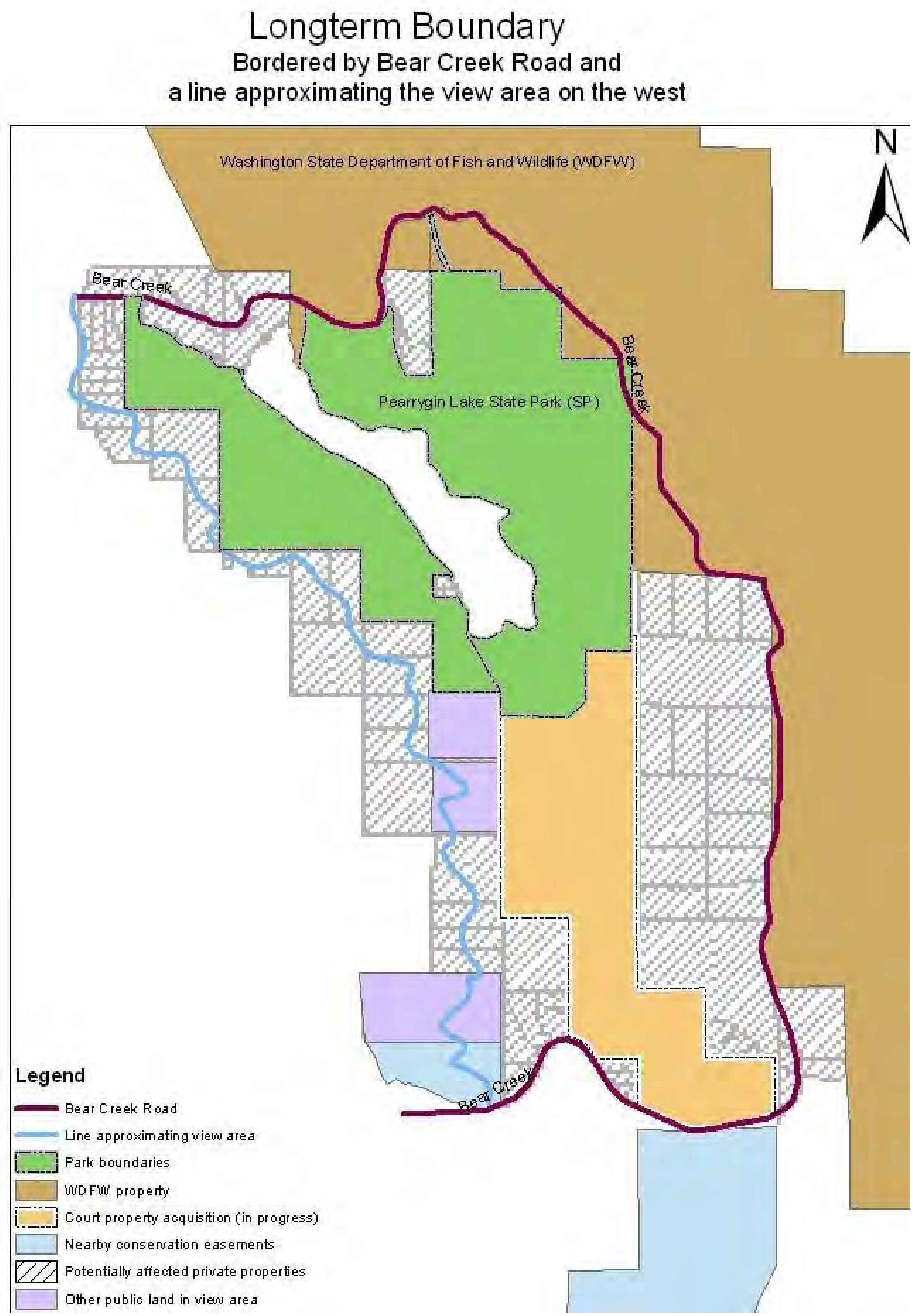
The team’s recommended *long-term* boundary (see figure 2 below) assumes that maintaining large tracts of land in State Parks’ ownership furthers both the conservation and recreation mission of the park.
In the case of Pearrygin Lake State Park, members of the community saw the benefits of a larger state park.

Advantages of recommended long-term boundary:

- Protects the park visitor's experience by managing development around Pearrygin Lake State Park.
- Provides a land base that would allow significant recreational opportunities while preserving natural and cultural resources.
- Separates the state land by types of use. The state lands on one side of Bear Creek Road would be managed by the Washington Department of Wildlife (WDFW) and on the other side it would be managed by State Parks1. Please note that only preliminary discussions have occurred between the two state agencies and inclusion of WDFW managed land within the long-term boundary does not indicate concurrence by WDFW.

[1] The exception would be the boat launch area, which would remain under the management of Washington State Department of Fish and Wildlife

Figure 2


Longterm Boundary
Bordered by Bear Creek Road and
a line approximating the view area on the west
N
Washington State Department of Fish and Wildlife (WDFW)
Bear Creek
Pearrygin Lake State Park (SP)
Bear Creek
Bear Creek
Legend
Bear Creek Road
Line approximating view area
Park boundaries
WDFW property
Court property acquisition (in progress)
Nearby conservation easements
Potentially affected private properties
Other public land in view area

Land Classification

Within the *long-term* boundary, staff developed recommendation for classifications. Land classification is like internal zoning for the park (see Appendix A) and is regulated by WAC 352-16-020, which reads:

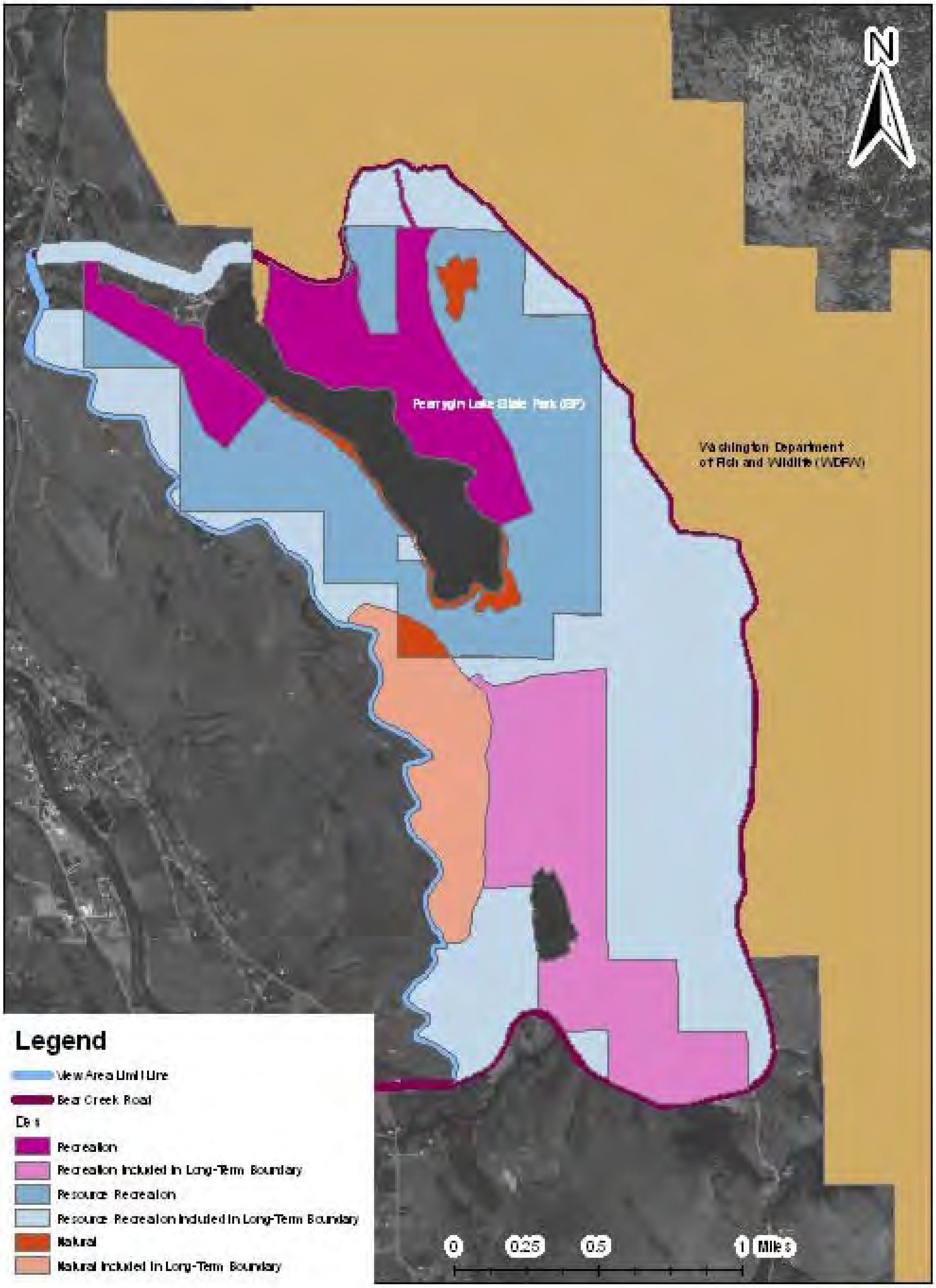
> *State park areas are of state-wide natural, cultural, and/or recreational significance and/or outstanding scenic beauty. They provide varied facilities serving low-intensity, medium intensity, and high intensity outdoor recreation activities, areas reserved for preservation, scientific research, education, public assembly, and/or environmental interpretation, and support facilities.*

The Commission adopted the a land classification for Pearrygin Lake State Park that is a combination of Recreational (red,) Resource Recreation (blue) and Natural (orange) Areas . The lighter shades of blue, red and orange indicate that the property is not currently owned by State Parks, but is in the long-term boundary.

These land classifications provide for mule deer priority habitat on the east side of the long-term boundary and a buffer of low-intensity uses along the boundary of the property. Natural Areas are designated around wetlands and intact ecosystems.

An additional recreational area will be added to the northwest area of the state park when the equestrian facility is located.

Figure 3: Pearrgyin Lake State Park Land Classification and Long-Term Boundary Map.



SECTION 5: PARK ISSUES AND MANAGEMENT APPROACHES

This section of the document outlines the main natural, cultural, and recreation / facility resource issues identified by the public and staff during the CAMP and master planning processes, and suggested management approaches to address them (see Tables below). As in any real world situation, some issues do not neatly fit into any one of these three categories, while others may span more than one. Some license has been taken for the sake of consistent presentation. Addressing these issues will in almost all cases involve Park staff working with Regional Stewardship, Environmental, and Planning staff. Additional stakeholder involvement is also anticipated, and may include (but not be limited to): HQ service centers, sister natural resources agencies (including the Department of Natural Resources, Washington Department of Fish and Wildlife, Washington Department of Ecology, Office of Archeology and Historic Preservation), local government institutions (weed control boards, permitting), non-profit organizations (Washington Native Plant Society, The Nature Conservancy, Audubon), the Tribes, institutions of higher education, and adjacent land-owners and interested citizens. All management actions will be consistent with the laws and policies[2] governing the agency, in addition to all federal, state, and local regulations. As the issues and their management approaches are addressed in the future, associated materials (e.g., inventories, plans, monitoring records) will be added as appendices to this document.

[2] Specifically, for natural resources: Protecting Washington State Parks' Natural Resources - A Comprehensive Natural Resource Management Policy (Commission Agenda Item F-11, December 2004); and for cultural resources: Cultural Resources Management Policy (Commission Agenda Item E-1, October 1998 + three amendments).

Park Management Issues

The tables below are a listing of park management issues identified through the public planning process for Pearrygin Lake State Park. This information will ultimately form the basis of the park's management plan, but should be considered preliminary at this time.

Readers should note that the sum of all of the management approaches represents a significant staff workload and may also create very high expectations among agency staff and park stakeholders. Clearly, completing or even beginning all approaches in the short-term is not feasible with existing resources. This plan should be seen as a "to do" list where items will be prioritized as staff and financial resources permit.

Natural Resources	
Issue	**Management Recommendations**
Fire prevention preparedness	Review the current state park fire plans and update those plans to include new property acquisitions.
Improvement of water quality	Cooperate with agencies that monitor water quality, and when a problem is identified, work to find a solution. This issue had to do with a complaint about boats leaking petroleum products in the lake. Boat management on the lake is the jurisdiction of Okanogan County. A search of water quality data from the Department of Ecology found no water quality problems for Pearrygin Lake.
Inventory of natural plant and animal communities	Complete an inventory of plant and animal communities in the state park.
Land Classification	Properties within the long-term boundary would be classified as Resource Recreation Areas, except for the following: Natural Areas: ▪ Wetland on the south end of the lake ▪ Aspen forest southeast of Pearrygin Lake and on the west edge of the long-term boundary ▪ Wetland area near the entrance road to the east developed area Recreation Areas: ▪ East side of the lake: o the west developed area, including most of the recent acquisitions (i.e., former Derry Resort and the alfalfa field) o the east developed area, including the campground, day-use areas and boat launch ▪ The existing golf course area with room for a nine-hole expansion ▪ West side of the lake in a tree covered area near the proposed trailhead ▪ A yet to be determined location for an equestrian facility
Maintenance of existing vegetation in the campgrounds	See "Planting grass, trees and shrubs at the west developed area." At the east developed area, some vegetation may be replaced by more drought resistant varieties, but most of the existing vegetation would be retained.

Natural Resources	
Issue	**Management Recommendations**
Planting grass, trees and shrubs at the west developed area	Plant drought-resistant native species appropriate to the area and its development are preferred. Vegetative landscaping will be similar to east developed area.
Protection of aquatic plant and animal communities	Classify wetlands on the south end of Pearrygin Lake as a Natural Area. Retain most of the shoreline in its natural state, except for in the developed areas. The campsites in the west developed area would be moved back from the shoreline in accordance with the Okanogan County Shoreline Management Program
Protection of natural plant and animal communities	Protect natural plant and animal communities through appropriate land classification and sensitive development as discussed above in "Protection of aquatic plant and animal communities" and "Protection of upland plant and animal communities." Commission policies concerning natural resources apply, including: ▪ 03-01 Critical Areas Policy (available upon request) ▪ 04-01 Natural Resource Management Policy (available upon request)
Protection of threatened and endangered species	Protect threatened and endangered species on State Park property by first identifying any known species and then developing a protection plan.
Sustainability in the new area development	These and other sustainability methods would be incorporated into development designs and park operation, when feasible: ▪ Construct using low-water toilets and sinks ▪ Continue the recycling program ▪ Expand upon electrical energy conservation features ▪ Develop fuel conservation practices
Weed management of the new and existing properties	Complete a weed management plan based on plant inventories of the new and existing properties. Incorporate the following suggestions from Okanogan County into the weed management plan: ▪ Treatment of the parking areas and access roads annually to reduce the spread of noxious weeds in and out of the area ▪ Replant disturbed soil with suitable certified grass mixture to compete with noxious weeds ▪ Develop effective management practices to control noxious weeds on roads and trails ▪ Request weed free forage in the equestrian facility and for three days before coming to the facility ▪ Include a weed wash cleaning facility for aquatic equipment (e.g., boats and jet skis) at the boat launch. ▪ Post signs to educate park users regarding noxious weeds and encourage reporting to the Okanogan County Noxious Weed Control Board ▪ Research any introduced vegetation to determine whether it is invasive and all seed mixtures should be certified noxious weed-free seed.

Natural Resources	
Issue	**Management Recommendations**
Wildlife viewing and environmental interpretive opportunities	Develop programs and bulletin boards in the state park that describe the natural resources. Establish wildlife viewing opportunities and provide interpretation in suitable areas, such as the south end of the lake. Work with local naturalists to establish interpretive walks and programs that would help park visitors appreciate the natural resources in the state park, but also ensure that those resources are not jeopardized. Enhancement of the park interpretive program may be in cooperation with other businesses in the area.

Cultural Resources	
Issue	**Management Recommendations**
Identification and protection of Native American archaeological and cultural resources	Conduct archaeological survey prior to disturbance of areas affected by development. Continue to consult with Tribes that may have an interest in the archaeological and traditional cultural properties in the state park. State Parks staff will follow the direction contained in the Washington State Parks and Recreation Commission's Cultural Resources Policy 12-98-1.
Interpretation of Methow Valley history	Seek information about Pearrygin Lake State Park's role in the interpretation of Methow Valley history. Some of these comments had to do with what State Parks would do with the Graves farmhouse on the Court Property. An interpretation plan is recommended, if the property is acquired. However, most of the buildings would probably be dismantled and photo documented, because they are not eligible for the state and national historic registers.

Recreational Resources	
Issue	**Management Recommendations**
Access of water-front campsites to lake	Work with Okanogan County staff to clarify the Master Program for Shoreline Management rules. The program restricts campgrounds within 100 feet of the lake and creates a 200 foot wide Conservancy Environment.
Acquisition plan for protection of the Bear Creek corridor to Davis Lake	Acquire, seek conservation easements or otherwise seek to protect properties that are not in public ownership and/or that lack conservation easements with a coalition composed of the Washington Department of Fish and Wildlife (WDFW), the Methow Conservancy and other interested individuals or organization. The following areas would be targeted: ▪ Current acquisitions in progress for the Yockey and Court Properties ▪ All properties between the state park and WDFW from the southeast part of Pearrygin Lake State Park west of Bear Creek Road ▪ A buffer approximately 200 feet on both the north and south sides of Bear Creek Road between East Chewuch Road and Pearrygin Lake State Park ▪ Public and private properties along a line that approximates the eastern "military crest" of Studhorse Mountain
Adding more cabins and yurts	Build a combination of utility and rustic cabins in the west developed area. Yurts would not be added. Property view sheds are of primary importance from the state park. However, basic cabins may be developed on the west side of the lake, provided that they are in the tree-covered area. Vault toilets would provide sanitation for those cabins. Efforts should be made to connect the cabin sites on the west side of the lake to the main state park.
Affect of land acquisition on county and local government	Work with county and local government during acquisition planning process. Develop appropriate facilities and activities that are assets to the local community from government owned lands.
Balance of issues from the various public groups	Listen to everyone that participates in the planning process.
Better and more showers	The bathrooms and showers would be upgraded as the west developed area is redeveloped.
Better enforcement of State Parks rules, including quiet hours	Due to a desire to provide a quality experience for the visitor, a new ranger position has been added to the staff.

Recreational Resources	
Issue	**Management Recommendations**
Boat management on the lake	Okanogan County has jurisdiction over boat use on the lake. State Parks would not pursue changes to boat use regulations on the lake, but would work with others to improve habitat protection along the lake and cooperate with the county enforcement of regulations. State Parks would also work with the County to develop a no-wake area near the relocated swim beach.
Choosing to improve Pearrygin Lake State Park over other state parks	The Washington State Parks and Recreation Commission has identified the Centennial 2013 Plan (http://www.parks.wa.gov/Centennial2013/) as its way to make improvements at all of the state parks. In addition, the Commission recently chose Pearrygin Lake State Park as one of its "Legacy" priorities.
Collaboration instead of competition with local businesses	Continue to work with the local chambers of commerce and local businesses to find ways to be mutually supportive. Referrals to local businesses and sensitivity to how the park fits into the community would continue the already good relationship.
Configuration of the campsites and road system	The road system would be dependent upon the number and types of facilities. Some conceptual drawings are available. (Campsites are discussed in "Number, location and type of campsites and cabins below.)
Connecting the state park to other trails	Support and actively plan with partners a regional trail system that connects to trails within the state park, where natural and cultural resources are not adversely impacted. Examples of a regional trail system would include: ▪ Trails on Washington Department of Fish and Wildlife (WDFW) property ▪ The Okanogan County Trail Plan ▪ Connection(s) to Winthrop
Connecting the state park to Winthrop	See "Connecting the state park to other trails"
Construct an equestrian facility	There are several sites under consideration for an equestrian facility. The planning team recommends that the choice of a 5-10 acre site for the equestrian facility be postponed until: ▪ An environmental impact assessment is completed on each of the potential equestrian facility sites. ▪ An agreement is reached on the location of the trail system on nearby public lands. State Parks will continue to work with trail advocates, Okanogan County, Washington State Department of Fish and Wildlife, the USDA Forest Service and others to develop the trails plan.
Contribution of the state park to the community	The state park contributes significantly to local economies throughout the state.[3]

[3] Runyan, Dean Associates, "Economic Impacts of Visitors to Washington State Parks," June 2002.

Recreational Resources	
Issue	**Management Recommendations**
Control the hornets	Park staff spray hornet nests as they are located. Hornet traps are already in use.
Cooperative management with the Washington Department of Fish and Wildlife (WDFW)	Continue to meet regularly with local WDFW staff to discuss management issues, such as maintenance of the pump house and hunting season operations.
Create a design standard for the state park	Develop design standard for this park.
Creating access points to new state parks property	Provide access to new state park property through a trail system with additional parking areas, where needed.
Creation of a construction budget and timeline	Create budget documents as part of the public works projects that come from an approved *long-term* plan. At the November 2005 meeting of the Washington State Parks and Recreation Commission Pearrygin Lake State Parks was designated the "legacy" priorities in the Centennial 2013 Plan (http://www.parks.wa.gov/commtg.asp .)
Developing moorage on the lake	Develop short term overnight moorage for park visitors. The moorage would be rented on a daily or weekly basis. Space for fishing would be included. The development of moorage would depend upon the results of a business plan, Okanogan County Master Program for Shoreline Management determinations and environmental review by regulatory agencies.
Development of a single entrance road	Develop a single entrance to the state park at the west developed area and a welcome center so that visitors can be greeted when they arrive and would know how to reach park staff.
Dry storage of boats	No dry boat storage.
Eliminate the parking fee	The fee was eliminated by the Washington State Legislature. For more information, please see http://www.parks.wa.gov/public.asp
Events at the state park	Develop an outdoor stage and work with the Methow Arts Alliance and other organization to encourage events including those that promote diversity.
Fishing on the lake, including fishing docks	The moorage dock in the west developed area would be also used as a fishing dock on the lake. Construction of a moorage dock would depend upon additional analysis on the impact to other forms of recreation, the Okanogan County Master Program for Shoreline Management determinations and the environmental review by regulatory agencies.

Recreational Resources	
Issue	**Management Recommendations**
Foundation or Friends of Pearrygin State Park group to collect donations to help improve facilities	Develop a foundation or a Friends of Pearrygin Lake State Park group to help implement the plan as approved by the Washington State Parks and Recreation Commission. Partnerships are a central theme in the Commission's Centennial 2013 Plan. Similar groups in other state parks have helped make improvements and they would be welcome at Pearrygin Lake State Park.
Four season park open to public	One of State Parks management objectives is to create a state park that would be available to the public on a year-around basis.
Golf Course management and development	The staff recommendation is that the golf course would be expanded, if a private operator can be found that will finance the project. Until that time, the nine-hole golf course would remain open through an agreement with a private operator for an indefinite period. State Parks would limit its investment to maintenance projects and not make major improvements.
Improvement of the central reservations system	Work with the central reservation system to make sure that park visitors have adequate information about the camping facilities.
Improvement of utilities and facilities at the existing campsites	Upgrade tired facilities as part of future capital projects.
Increase privacy around campsites	Review campsites that were identified as having privacy problems because trails that are too close and insufficient screening. Improve privacy at those campsites.
Increase the number of waste receptacles or move them to be more convenient	Review the park visitor complaints about waste receptacles to determine whether a certain area needs additional receptacles.
Lake level affect on recreation	Advocate for the current lake level. The campgrounds and other facilities are on land that is flat and at the same relative elevation as the lake, raising the lake level to increase irrigation capacity would eliminate many of the existing campsites and adversely affect potential trails.
Location and number of boat launches	Eliminate existing boat launch currently located at the West developed area. Retain existing boat launch with necessary improvements.

Recreational Resources	
Issue	**Management Recommendations**
Location, number and configuration of swimming areas	Relocate swim beaches to one central location and keep the shoreline as natural as possible, reduce the impact of the boaters on the swimmers, and address the erosion issue. State Parks would work with the County to designate the area as a no-wake zone. Research of the lake bathymetry and sediment deposition would be needed to determine the appropriate location for the swim area.
Location, services and development of the store	Relocate the store to a central location so that it can provide additional services, such as non-motorized boat rentals (e.g., canoes, paddle boats and kayaks), food services and groceries for campers.
More full or partial hookup campsites with some campsites along the lake	The goal for the ratio of hook-up sites to non-hook up sites would match current recreational trends which are currently 65% hook-up to 35% non-hook up campsites. (Please see "Access of water-front campsites to lake" for the recommendation for campsites along the lake.)
Noise reduction in the state park	Park staff would continue to enforce WAC 352.32, regarding peace and quiet within the state parks.
Number, location and type of campsites and cabins (see "Adding more cabins and yurts below.)	The planning team recommends that the campground be reconfigured to allow spacing and vegetation similar to the west developed area. The actual size of the redeveloped campground depends upon additional studies. A combination of rustic and utility cabins will be added to the developed area.
Off-leash area for dogs	Maintain the current rules for dogs. The desire to have a place to walk dogs off-leash is very understandable. Unfortunately, dogs off-leash sometimes causes problems for wildlife and other campers.
Okanogan County zoning	Work with Okanogan County and through the Planned Development procedure (Chapter 17.19 County Code) for Pearrygin Lake State Park.
Operation of the go-kart track	Use the go-kart area for other recreational uses.
Outdoor covered area for washing dishes	Review site conditions and consider options.
Pet waste control	Install pet waste scoopers in the state park.
Proper staffing of the state park	Balance new developments with the ability to properly maintain State Park facilities.

Recreational Resources	
Issue	**Management Recommendations**
Provide an outdoor stage for movies and other programming	Construct an outdoor stage for performances, events and interpretive programs. Work with the Methow Arts Alliance and other groups during the design process and enlist community resources to implement the design.
Reduce conflict between trail users	The issue was merged into “Trail management and development in the state park.”
Reduce light pollution from the state park	Review lighting options and incorporate fixtures in the new development that direct light away from the skies.
Retaining the qualities of Pearrygin Lake State Park while incorporating the new properties	The west developed area would be redesigned to be more like the older part of the state park.
Should State Parks and the Washington Department of Fish and Wildlife (WDFW), make boundary line adjustments to differentiate management areas?	Seek boundary line adjustments with the Washington Department of Fish and Wildlife (WDFW) so that State Parks would be able to consolidate its management to the west side of Bear Creek Road and WDFW would have management control of the east side. State Parks would not seek to obtain the WDFW boat launch on Pearrygin Lake.
Shuttle connecting state park to Winthrop	Consider proposals to link Winthrop to Park via shuttle service.
Signage in the state park, particularly when the campgrounds are physically separated	Review the signage along Bear Creek Road that directs people to the west and east developed areas and make improvements as needed.
Tent-only campsites that are separate from RVs	Evaluate the use and explore for areas appropriate for tent-only camping.

Recreational Resources	
Issue	**Management Recommendations**
Trail management and development in the state park	Develop a trail system for hikers, equestrians and bicyclists riders that would connect key points of the state parks' *long-term* boundary. The trail system could be designed so that the different uses (i.e., equestrians, bicyclists and hikers) could be separated from each other. It may be difficult to allow both a hiking and biking trail and an equestrian trail on the west side of the lake. In that case, the planning team recommends that the hiking and biking trail have priority over the equestrian trail. Equestrian trails are planned for the east side of the state park. Investigate available community resources that would help plot the proposed trail using Global Positioning System (GPS) equipment.
Upgrading and location of facilities at the west developed area	Upgrade the west developed area. The west developed area obviously needs additional work. State Parks staff made huge efforts to get the area ready for the 2005 camping season, because of comments received from the community and customers of the former resort. Further plans are included in the master plan for Pearrygin Lake State Park.
View shed protection between the state park and East Chewuch Rd.	Merged into "Acquisition plan for protection of the Bear Creek corridor to Davis Lake"
What will happen to the Fowler Road?	Depending upon the trail configuration and facilities on State Parks' property on Studhorse Mountain, it would be advantageous to work with landowners to relocate the existing road.
Website information on the state park and facilities	Review the website on Pearrygin State Park and forward any needed updates to the Web manager.
Wireless Internet or cable at the state park	Review and consider concession proposals to provide wireless Internet in the state park. Wireless Internet could provide opportunities to interpret local features including community programs. It could be a tool to further integrate the state park into the town and region.

SECTION 6: OTHER PARK PLANS

Previously prepared plans provide additional guidance for the management of specific resources or activities in a park. Examples of these types of plans include threatened or endangered species management plans, cultural resource management plans, and trail use and development plans.

Park master plans are generally oriented toward capital facilities development, but also commonly provide policy direction. The relationship between this plan, other existing plans, and recommended future plans should be seen as iterative. As new information is derived from more detailed resource-specific planning, existing plans should be reviewed and modified to reflect changed circumstances. A list of inventory materials is included as Appendix C.

No single plan should be vested with ultimate authority, but rather, the on-going process of creating new plans and revising existing plans should be seen as forming an increasingly comprehensive base of policy direction. The role of this document is to serve as an ‘umbrella’ under which all park-related plans are referenced. A listing and location of existing plans prepared for Pearrgyin Lake State Park is included in Appendix D

APPENDIX A: WASHINGTON STATE PARKS LAND CLASSIFICATION SYSTEM

WAC 352-16-020 Land classification system. State park areas are of statewide natural, cultural, and/or recreational significance and/or outstanding scenic beauty. They provide varied facilities serving low-intensity, medium intensity, and high intensity outdoor recreation activities, areas reserved for preservation, scientific research, education, public assembly, and/or environmental interpretation, and support facilities. They may be classified in whole or part as follows:

(1) Recreational areas are suited and/or developed for high-intensity outdoor recreational use, conference, cultural and/or educational centers, or other uses serving large numbers of people.

(2) Resource recreation areas are suited and/or developed for natural and/or cultural resource-based medium-intensity and low-intensity outdoor recreational use.

(3) Natural areas are designated for preservation, restoration, and interpretation of natural processes and/or features of significant ecological, geological or paleontological value while providing for low-intensity outdoor recreation activities as subordinate uses.

(4) Heritage areas are designated for preservation, restoration, and interpretation of unique or unusual archaeological, historical, scientific, and/or cultural features, and traditional cultural properties, which are of statewide or national significance.

(5) Natural forest areas are designated for preservation, restoration, and interpretation of natural forest processes while providing for low-intensity outdoor recreation activities as subordinate uses, and which contain:
   (a) Old-growth forest communities that have developed for one hundred fifty years or longer and have the following structural characteristics: Large old-growth trees, large snags, large logs on land, and large logs in streams; or
   (b) Mature forest communities that have developed for ninety years or longer; or
   (c) Unusual forest communities and/or interrelated vegetative communities of significant ecological value.

(6) Natural area preserves are designated for preservation of rare or vanishing flora, fauna, geological, natural historical or similar features of scientific or educational value and which are registered and committed as a natural area preserve through a cooperative agreement with an appropriate natural resource agency pursuant to chapter 79.70 RCW and chapter 332-60 WAC.

WAC 352-16-030 Management within land classifications. (1) The director shall develop management guidelines for each land classification listed in WAC 352-16-020. The guidelines shall provide specific direction for each classification, outlining the philosophy of each classification, its appropriate physical features, location, allowed and prohibited activities, and allowed and prohibited developments. (2) Nothing in this section shall be construed to allow uses that are otherwise prohibited, nor prohibit uses that are otherwise expressly allowed, by the commission, this code, or by statute.

Land Classification Management Guidelines
Recreation Areas

TITLE	DEFINITION	PHILOSOPHY	PHYSICAL FEATURES	LOCATION	ACTIVITIES	DEVELOPMENTS
Washington State Parks Recreation Areas	State Parks Recreation Areas are suited and/or developed for high-intensity outdoor recreational use, conference, cultural and/or educational centers, or other uses serving large numbers of people.	State Parks Recreation Areas are to respond to the human need~~s~~ for readily available areas for outdoor recreation and facilities to congregate for education, artistic expression and other ennobling pursuits. They are to provide a variety of outdoor recreational, educational, artistic, and cultural opportunities to large numbers of participants. Primary emphasis is on the provision of quality recreational services and facilities with secondary recognition given to protection of the areas natural qualities.	State Parks Recreation Areas physiographic features such as topography, soil type, drainage, etc., shall be adaptable to varied types of intensive uses and development. An attractive natural setting is desirable, however, human-made settings are acceptable. There are no specific size criteria.	State Parks Recreation Areas generally are made, not found. They shall be located throughout the state with primary emphasis to service major centers of urban populations and/or outstanding recreational tourist attractions. Scenic and inspirational values shall be considered but are secondary to the site adaptability and population criteria. When part of a large diverse park, recreation areas should be sited in proximity to public roads and utilities.	State Parks Recreation Areas may allow and provide for a wide variety of indoor and outdoor day, weekend and vacation activities. Provision may be made for high intensity participation in camping, picnicking, trail use, water sports, winter sports, group field games, and other activities for many people Off-trail equestrian and/or bicycle use may be appropriate in selected areas if approved by the commission. Activities requiring high levels of social interaction are encouraged.	State Parks Recreation Areas shall provide appropriate facilities and services for the participation and enjoyment of high concentrations of outdoor recreationists and/or participants in indoor educational, cultural and artistic activities. A high degree of development is anticipated. Facilities may include road and parking networks, swimming beaches, full service marinas, trails, bathhouses, artificial lakes and pools, play fields, large sanitary and eating facilities; standard and utility campgrounds, stores, picnic grounds, group shelters, conference centers, environmental learning centers, hostels, and administrative support facilities.

Land Classification Management Guidelines
Resource Recreation Areas

TITLE	DEFINITION	PHILOSOPHY	PHYSICAL FEATURES	LOCATION	ACTIVITIES	DEVELOPMENTS
Washington State Parks Resource Recreation Areas	State Parks Resource Recreation Areas are suited and/or developed for natural and/or cultural resource-based medium- and low-intensity recreational use.	State Parks Resource Recreation Areas are sites where the high quality of a particular natural or cultural resource or set of such resources is the lure for human recreation. Thus, the rationale for recreation is based on the value of attractive natural or cultural resources. Management of these areas must stress the centrality of preserving the quality of the natural and cultural resources while allowing appropriate and sustainable levels of human use and enjoyment.	State Parks Resource Recreation Areas have a variety of physiographic features. While they may contain areas of environmental sensitivity, most portions of each area will be able to withstand low- to medium-intensity recreation use without significant environmental degradation.	State Parks Resource Recreation Areas may be located anywhere in the state where natural or cultural factors produce land and water sites particularly suited for recreation in a natural setting. Access to these sites should be reasonably proximate to major urban centers, but some access restriction may be necessary to avoid overuse of resources. Within large diverse parks, these areas should be located at least a moderate distance from public roads and high use intensity areas, while still maintaining reasonable public access for their intended use.	State Parks Resource Recreation Areas provide opportunities for low- and medium-intensity recreational experiences including, but not limited to, picnicking, primitive camping, a variety of recreational trail experiences, interpretive facilities, historic/cultural exhibits, nature observation, photography, orienteering, kayaking, canoeing, floating, and fishing. Off-trail equestrian and/or bicycle use may be appropriate in selected areas if approved by the commission. Basketball, tennis, organized group sporting activities requiring formal sports fields, commercial-sized piers and docks, standard and utility camping, indoor accommodations and centers, developed swimming areas, and other similarly intense uses are not appropriate. Scientific research is permitted.	State Parks Resource Recreation Areas development shall be permitted to the extent necessary to serve allowed activities. Parking, sanitary facilities, and other ancillary developments and support facilities should be constructed in a manner that is consistent with the site's ability to manage environmental change.

Land Classification Management Guidelines
Natural Areas

TITLE	DEFINITION	PHILOSOPHY	PHYSICAL FEATURES	LOCATION	ACTIVITIES	DEVELOPMENTS
Washington State Parks Natural Areas	State Parks Natural Areas are designated for preservation, restoration, and interpretation of natural processes and/or features of significant ecological, geological or paleontological value while providing for low-intensity outdoor recreation activities as subordinate uses.	State Parks Natural Areas are to respond to the human need for readily available "conservatories" of nature and open spaces. Emphasis is directed toward nature and the conservation of native flora and fauna, special geologic or paleontologic resources, and the natural amenities of the area. Human wants for other than naturally existing educational and recreational opportunities are considered secondary to nature's requirement for the sustained maintenance of its natural balances, or the preservation of special geologic or paleontologic features.	State Parks Natural Areas have a variety of topography and features to provide a diversified natural environment with interesting but not necessarily unique flora and fauna, or geologic or paleontologic features. Where classification is based on biological considerations, sites should consist of land areas large enough to maintain natural biological processes in a nearly undeveloped state and provide users with a feeling of solitude and tranquility, and an opportunity to view nature in its "uncontrolled" form. They may be partially or wholly on land, subterranean, or part of the marine environment.	State Parks Natural Areas are not "made", but rather currently exist due to historical circumstances that have resulted in little or no human interference in the natural environment. Those areas most desirable in terms of physical features and size usually are "found" and "held" against creeping encroachments and raising land values. They often become over used and "lost" as populations spread around them. As a part of the overall system, these areas should be geographically spread throughout the state. When classifying specific park areas, consideration must be given to the ability to adequately manage the areas against undesirable human encroachment.	State Parks Natural Areas provide opportunities for outdoor recreation on designated trails. Those trails may be developed and used only to the extent that they do not significantly degrade the system of natural processes in a classified area. Hiking, non-groomed cross-country skiing, snowshoeing, or other trail uses of similar impact to natural systems and providing a compatible recreational opportunity, may be permitted, after consultation with appropriate local, state, federal and tribal resource management agencies, and upon a finding by the agency that such trails are not likely to significantly degrade natural processes. Relocation of existing equestrian, bicycle, nordic track or other similar trails into a natural area may be permitted upon a finding by the director that such relocation is for the purpose of reducing overall resource impacts. All trails may be moved, redesigned, closed and/or removed upon a finding that their use is causing significant degradation to the system of natural processes. Technical rock climbing requires authorization by the commission. Off-trail use for nature observation, photography, cross-country skiing, harvesting of mushrooms and berries and similar uses are permitted to the degree that they do not significantly degrade natural processes. Scientific research is permitted.	State Parks Natural Area development shall be limited to facilities required for health, safety and protection of users and features consistent with allowed activities. Facilities to enhance public enjoyment shall be limited to primitive items such as trails, trail structures and minor interpretive exhibits. All improvements shall harmonize with, and not detract from, the natural setting. Parking and other trailhead facilities should be located outside of a classified area.

Land Classification Management Guidelines
Heritage Areas

TITLE	DEFINITION	PHILOSOPHY	PHYSICAL FEATURES	LOCATION	ACTIVITIES	DEVELOPMENTS
Washington State Parks Heritage Areas	State Parks Heritage Areas are designated for preservation, restoration, and interpretation of outstanding, unique or unusual archaeological, historical, scientific, and/or cultural features, and traditional cultural properties, which are of statewide or national significance.	State Parks Heritage Areas are designated to preserve and/or interpret selected areas or features for the education and enjoyment of the public, an area's intrinsic cultural value, and/or for scientific research.	State Parks Heritage Areas vary in size and physiographic makeup according to their location and reason for existence. Historic landscapes may require relatively large acreage while archaeological sites may be measured in square feet.	State Parks Heritage Areas usually are located where they are found or the feature exists. However, in some instances relocation or re-creation of artifacts, resources or facilities is possible. In these situations they may be located in appropriate settings and concentrated near major population centers and along primary travel routes.	State Parks Heritage Area activities shall generally be limited to those directly associated with the interpretation of the area or feature, and the education of the patrons. Picnicking, recreational trails, and other low- to medium-intensity recreation uses may be allowed if they do not detract from the principal purpose of the area, its setting, structures, sites and objects.	State Parks Heritage Area development shall generally be limited to that necessary for the protection and interpretation of the area or feature, and the education and safety of the patrons. Sanitary facilities, recreation trails, and picnicking facilities may be provided in a manner which does not detract from the aesthetic, educational or environmental quality of the area, its setting, structures, sites or objects, or, if applicable, its value for scientific research.

Land Classification Management Guidelines
Natural Forest Areas

TITLE	DEFINITION	PHILOSOPHY	PHYSICAL FEATURES	LOCATION	ACTIVITIES	DEVELOPMENTS
Washington State Parks Natural Forest Areas	State Parks Natural Forest Areas are designated for preservation, restoration, and interpretation of natural forest processes while providing for low-intensity outdoor recreation activities as subordinate uses, and which contain: (a) Old-growth forest communities that have developed for 150 years or longer and have the following structural characteristics: Large old-growth trees, large snags, large logs on land, and large logs in streams; or (b) Mature forest communities that have developed for 90 years or longer; or Unusual forest communities and/or interrelated vegetative communities of significant ecological value.	State Parks Natural Forest Areas are places where human access to and interpretation and enjoyment of natural forest processes are limited to those activities and facilities that do not significantly degrade natural forest processes. Public access into these areas emphasizes appreciation of nature through experiencing nature. The principal function of these areas is to assist in maintaining the state's bio-diversity while expanding human understanding and appreciation of natural values.	State Parks Natural Forest Areas have a variety of topographic and vegetative conditions. They are generally large enough (300 or more acres) to contain one or more distinct and relatively intact vegetative communities. Smaller areas may be appropriate if representative of a unique or unusual forest community. Desirably, they are part of a large system of open space, wildlife habitat, and vegetative communities that provide a good opportunity for long-term ecosystem sustainability.	State Parks Natural Forest Areas may be located anywhere in the state where natural factors produce forest vegetative cover. These areas are not "made", but rather currently exist due to historical circumstances that have resulted in little or no human interference in natural forest progression. As a part of an overall system, these areas should be geographically spread throughout the state, recognizing that maintenance of bio-diversity is one of the primary functions of their classification. When classifying specific park areas, consideration must be given to the ability to adequately manage the areas against undesirable human encroachment.	State Parks Natural Forest Areas provide opportunities for outdoor recreation on designated recreation trails. Those trails may be developed and used only to the extent that they do not significantly degrade the system of natural forest processes in a classified area. Careful design of recreation trails should match intended uses, to maintain consistency with the purpose and philosophy of the classification. Hiking, non-groomed cross-country skiing, snowshoeing, or other trail uses of similar impact to natural systems and providing a compatible recreational opportunity, may be permitted, after consultation with appropriate local, state, federal and tribal resource management agencies, and upon a finding by the agency that such trails are not likely to significantly degrade natural forest processes. Relocation of existing equestrian, bicycle, nordic track or other similar trails into a natural forest area may be permitted upon a finding by the director that such relocation is for the purpose of reducing overall resource impacts. All trails may be moved, redesigned, closed and/or removed upon a finding that they are causing significant degradation to the system of natural forest processes. Technical rock climbing requires authorization by the commission. Off-trail use for nature observation, cross-country skiing, photography, harvesting of mushrooms and berries and similar uses are permitted to the degree that they do not significantly degrade natural forest processes. Scientific research is permitted.	State Parks Natural Forest Areas development shall be limited to facilities required for health, safety and protection of users and features consistent with allowed activities. Facilities to enhance public enjoyment shall be limited to trails, trail structures, and minor interpretive exhibits. All improvements shall harmonize with, and not detract from, the natural setting. Parking and other trailhead facilities should be located outside of a classified area.

Land Classification Management Guidelines
Natural Area Preserves

TITLE	DEFINITION	PHILOSOPHY	PHYSICAL FEATURES	LOCATION	ACTIVITIES	DEVELOPMENTS
Washington State Parks Natural Area Preserves	State Parks Natural Area Preserves are designated for preservation of rare or vanishing flora, fauna, geological, natural historical or similar features of scientific or educational value and which are registered and committed as a natural area preserve through a cooperative agreement with an appropriate natural resource agency pursuant to chapter 79.70 RCW and chapter 332-60 WAC.	State Parks Natural Area Preserves are sites where human access is limited to educational and scientific purposes. The principal function of these areas is to preserve natural ecosystems or geologic features of statewide significance. Public access for recreation must be subordinate to the principal function of the classification.	State Parks Natural Area Preserves have a variety of topographic and vegetative conditions. They are generally large enough (300 or more acres) to contain one or more distinct and intact ecological communities. Smaller areas may be appropriate if representative of a unique or unusual ecological community or geologic feature. They may be partially or wholly on land, subterranean, or part of the marine environment. Desirably, they are part of a large system of open space, wildlife habitat, and vegetative communities that provide a good opportunity for long-term ecosystem sustainability.	State Parks Natural Area Preserves may be located anywhere in the state where natural ecological systems or significant geologic features exist. These areas are not "made", but rather exist due to historical circumstances that have resulted in little or no human interference in the natural system. As a part of an overall system, these areas should be geographically spread throughout the state.	State Parks Natural Area Preserves provide opportunities for scientific research and education about natural systems, geologic features, sensitive, rare, threatened or endangered species or communities. Recreational use of existing or relocated trails may be permitted, provided that it can be clearly demonstrated that such use does not degrade the system of natural processes occurring in the preserve. Otherwise, trails are limited to administrative, scientific and organized educational activities and uses. No other activities are permitted.	State Parks Natural Area Preserves development shall be limited to access facilities for permitted activities and structures to inhibit general public access. No other facilities or structures are permitted.

Land Use and Land Classification Compatibility Matrix – Facilities

	Recreation	Resource Recreation	Heritage	Natural/Natural Forest Area	Natural Area Preserve*
Amphitheater	P	C	C	N	N
Archery/Target Range	C	C	N	N	N
Camping - Std and Util	P	N	N	N	N
Camping - Primitive	P	P	C	N	N
Camping - Adirondack	P	C	N	N	N
Camping - Horse-oriented	C	C	N	N	N
Camping - Water Trail	P	P	C	N	N
Children's Play Area	P	C	C	N	N
Day Use Picnic - Tables	P	P	C	N	N
Day Use Picnic - Group Shelter	P	N	C	N	N
Day Use Lodges/Centers	P	N	C	N	N
Environmental Learning Centers	C	N	C	N	N
Equestrian Facilities	C	C	C	N	N
Fields - Informal Play/Mowed	P	C	C	N	N
Indoor Accommodations	P	N	C	N	N
Interpretive - Centers	P	N	P	N	N
Interpretive - Kiosks	P	P	P	C	N
Interpretive Trail	P	P	P	P	C
Interpretive - Signs	P	P	P	P	C
Parking - Vehicles	P	P	C	N	N
Roads	P	P	C	N	N

Land Use and Land Classification Compatibility Matrix – Facilities (Continued)

	Recreation	Resource Recreation	Heritage	Natural/Natural Forest Area	Natural Area Preserve*
Sanitary: Comfort Stations	P	N	C	N	N
Sanitary: Composting/Vault	P	P	C	C	N
Sports Fields	C	N	N	N	N
Skiing - Alpine Facilities	C	C	N	N	N
Swimming Facilities	P	N	C	N	N
Trails - Hiking	P	P	P	P	C
Trails - Mountain Biking	P	C	C	N**	N
Trails - Equestrian	C	C	C	N**	N
Trails - Nordic Track Skiing	P	P	C	N**	N
Trails - C-C skiing	P	P	P	P	C
Trails - Snowmobile	P	C	C	N**	N
Trails - Paved non-motor	P	C	C	C	N
Water: Docks/Piers ≥ 10 boats	P	N	C	N	N
Water: Docks/Piers - < 10 boats	P	P	C	C	N
Water: Launch Ramps	P	C	N	N	N
Water: Hand Launch Areas	P	P	C	C	N
Water: Mooring Buoys	P	P	C	C	N

P (Permitted) - Use permitted with normal agency design review
C (Conditional) - Use may be permitted, but conditioned to assure design is compatible w/purpose of land classification and abutting classification objectives.
N (Not Permitted)- Use not permitted.
NA - Not Applicable
* All uses in a Natural Area Preserve must be specifically approved by the Park and Recreation Commission as part of a management plan.
**Relocation of existing trails into a natural or natural forest area is permitted per WAC 352-32-070(3) and WAC 352-32-075(2)(b).

Land Use and Land Classification Compatibility Matrix – Activities

	Recreation	Resource Recreation	Heritage	Natural/Natural Forest Area	Natural Area Preserve*
Farming/Orchards	C	C	C	N	N
Filming/Special Events	P	P	P	C	N
Grazing	C	C	C	N	N
Harvesting - Edible Fruiting Bodies	P	P	P	P	N
Harvesting - Mushrooms	P	P	P	P	N
Harvesting - Shellfish	P	P	P	P	N
Harvesting - Fish	P	P	P	P	N
Harvesting - Algae, etc.	P	P	P	P	N
Haying	P	P	P	N	N
Metal Detecting	P	P	C	N	N
Orienteering	P	P	C	N	N
Ocean Beach Driving	P	C	N	N	N
Off-Trail: Equestrian	C	C	C	N	N
Off-Trail: Hiking	P	P	P	P	N
Off-trail biking	C	C	C	N	N
Paragliding	P	P	C	N	N
Technical Rock Climbing	P	P	C	C	N

Land Use and Land Classification Compatibility Matrix – Activities (Continued)

	Recreation	Resource Recreation	Heritage	Natural/Natural Forest Area	Natural Area Preserve*
Water: Jet Skiing	P	C	N	N	N
Water: Kayak/Canoeing	P	P	P	C	N
Water: Power Boating	P	C	N	C	N
Water: White Water Boating	P	P	C	C	N
Water: Sailing	P	P	P	C	N
Water: Skiing	P	C	N	N	N
Water: Swimming	P	P	P	P	N
Water: Wind Surfing	P	C	C	N	N
Winter: Alpine Skiing	C	C	N	N	N
Winter: C-C Skiing (off-trail)	P	P	P	P	C
Winter: Mushing/Sled Dogs	C	C	C	N	N
Winter: Snowshoeing	P	P	P	P	C
Winter: Snowmobiling (off-trail)	P	P	C	N	N
Wood Debris Collection	P	P	P	N	N

P (Permitted) - Use permitted with normal agency design review
C (Conditional) - Use may be permitted with Commission concurrence, but conditioned to assure compatibility w/purpose of land classification and abutting classifications.
N (Not Permitted)- Use not permitted.
NA - Not Applicable
* All uses in a Natural Area Preserve must be specifically approved by the Park and Recreation Commission as part of a management plan.
**Relocation of existing trails into a natural or natural forest area is permitted per WAC 352-32-070(3) and WAC 352-32-075(2)(b).

APPENDIX B: CAMP PROJECT PLANNING PRINCIPLES

The seven basic principles used in the CAMP Project to ensure the long-term value of the end product to both the agency and the public stakeholders:

1) **Park management plans use a statewide format:** For efficiency and consistency among park management plans, State Parks has standardized management plans to include information that is applicable throughout the agency and a standard format for presenting park-specific information.

2) **Members of the public participate in development of park management plans.** Directly involving park stakeholders in producing and revising plans fosters better understanding of how their particular interests fit into the larger resource management context, while also giving them a stake in the plan's success. Public constituencies should be encouraged to participate in management planning both during the initial CAMP planning process and thereafter during annual open house meetings at the park.

3) **Park managers and park staff play an integral role in producing and revising park management plans.** Participation by park staff in planning is an essential part of ensuring that staff responsible for implementing this plan has a vested interest in making it succeed.

4) **Park management plans are the primary documents for communicating park resource management information.** Plans should be written to communicate clearly and concisely stewardship-related issues -- and the steps the agency should take to resolve them -- to the rest of the agency and to the public.

5) **Key administrative functions are incorporated into the park management planning process.** To ensure that park management plans are kept up to date, a process for proposing and justifying park capital and operating program requests has been incorporated into the management planning process.

6) **The Director approves park management plans.** Park management planning is an on-going process and plans should never be considered finished. Plans should however be considered "mature", ready to be published, and acted upon when they have been reviewed by the agency and approved by the Director or his/her designee.

7) **The review and approval process for future plan revisions will remain flexible.** After initial park management plans have been approved subsequent environmental, social, and political changes will necessitate that plans be revised. To ensure that revisions don't become mired in lengthy full agency review, a variable level approval process should be used. Staff at each level of the agency – park, region, division, and directorate -- must make a critical judgement as to whether a proposed plan revision requires review and approval at the next higher level.

APPENDIX C: LISTING OF PEARRYGIN LAKE STATE PARK RESOURCE INVENTORIES AND OTHER DESCRIPTIVE INFORMATION

Under Construction! Listing of resource inventories and other descriptive documents will be expanded as information is gathered.

Title	Author	Date	Location
" Pearrygin Lake State Park - Review of the Potential for Archaeology at the Proposed New Campground," State Parks letter report	Meatte, Dan and Kelley, Lisa,	December 12, 2005	Park Office Region Office

APPENDIX D: LIST OF PLANS FOR PEARRYGIN LAKE STATE PARK

Under Construction! List of all known plans for Pearrygin Lake State Park to be inserted here.

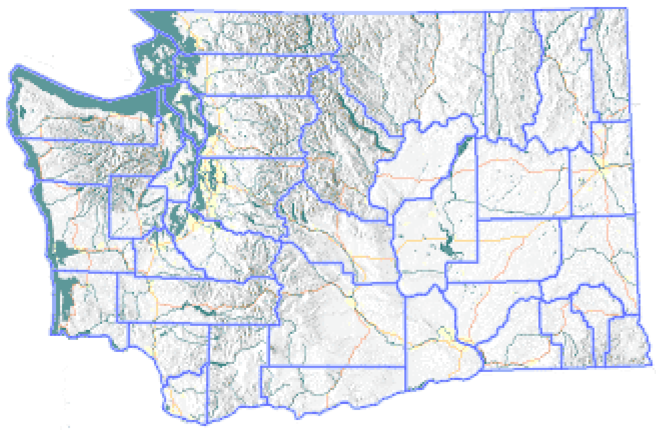
Title	Date	Approved by	Location
Pearrygin Lake State Park Master Facilities Concepts, Long-term	2006	Commission	Park and Region Offices
Business Plan	2006	Region Manager	Park and Region Offices; N drive
Integrated Pest Management Plan	2006	Region Manager	Park and Region Offices
Facilities Design Guidelines	2006	Region Assistant Manager, Park Manager, Region Planner and State Parks Architect	Park and Region Offices
Park Law Enforcement Plan		Region Manager	Park and Region Offices
Security of Assets Plan		Region Manager	Park and Region Offices
Park interpretive Plan		Region Manager	Park and Region Offices

Department of Ecology **Aquatic Plant Monitoring**

Ecology home > environmental information > aquatic plant monitoring

Pearrygin Lake

County	Okanogan
Latitude	48.49222
Longitude	120.1628
Ecoregion	Columbia Basin
years surveyed	2007, 1999, 1995
map link	



Species

scientific name	common name
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Cicuta douglasii	western water-hemlock
Elodea canadensis	common elodea
Elodea sp.	waterweed
Juncus sp.	rush
Lemna minor	duckweed
Lycopus asper	rough bungleweed
Lythrum salicaria	purple loosestrife
Myosotis laxa	small flowered forget-me-not
Myriophyllum sibiricum	northern watermilfoil
Najas flexilis	common naiad
Phalaris arundinacia	reed canarygrass
Polygonum amphibium	water smartweed
Potamogeton foliosus	leafy pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed

Schoenoplectus pungens	three-square bulrush
Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Solanum sp.	nightshade
Stuckenia pectinata	sago pondweed
Typha latifolia	common cat-tail
Typha sp.	cat-tail
Zannichellia palustris	horned pondweed

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Carex sp.	8/21/2007	1	Ecology	
Ceratophyllum demersum	8/21/2007	1	"	inflow area, protected cove
Chara sp.	8/10/1995	3	"	
"	8/11/1999	4	"	dominant
"	8/21/2007	4	"	crunchy feeling
Cicuta douglasii	8/21/2007	2	"	
Elodea canadensis	8/10/1995	3	"	
"	8/11/1999	2	"	most by inflow
Elodea sp.	8/21/2007	1	"	in inflow and outflow areas
Juncus sp.	8/11/1999	2	"	
"	8/21/2007	1	"	
Lemna minor	8/10/1995	1	"	
Lycopus asper	8/21/2007		"	fruiting
Lythrum salicaria	8/10/1995	2	"	scattered plants
"	8/11/1999	2	"	see map
"	8/21/2007	3	"	reportedly biocontrols released on it
Myosotis laxa	8/21/2007	1	"	
Myriophyllum sibiricum	8/10/1995	2	"	
"	8/11/1999	3	"	throughout
"	8/21/2007	3	"	dense in south end
Najas flexilis	8/10/1995	2	"	
"	8/11/1999	1	"	one floating fragment and one rooted plant at inflow
Phalaris arundinacia	8/21/2007	2	"	
Polygonum amphibium	8/10/1995	2	"	
"	8/11/1999	1	"	one seen at south end
"	8/21/2007	2	"	
Potamogeton foliosus	8/10/1995	1	"	
Potamogeton sp (thin leaved)	8/11/1999	2	"	most by inflow
"	8/21/2007	1	"	inflow area

Schoenoplectus pungens	8/21/2007		"	
Schoenoplectus sp.	8/21/2007	3	"	some in areas eroded by wave action
Scirpus sp.	8/10/1995	3	"	
"	8/11/1999	3	"	
Solanum sp.	8/21/2007	1	"	around launch
Stuckenia pectinata	8/10/1995	2	"	
"	8/21/2007	1	"	inflow area
Typha latifolia	8/11/1999	3	"	
"	8/21/2007	3	"	
Typha sp.	8/10/1995	2	"	
Zannichellia palustris	8/10/1995	1	"	
"	8/11/1999	1	"	at north end

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
2. "Source" is the organization that provided the data. "Ecology" refers to the Washington State Department of Ecology.

Washington State Department of Ecology

Questions or comments may be sent to Jenifer Parsons, Environmental Assessment Program, Central Regional Office.

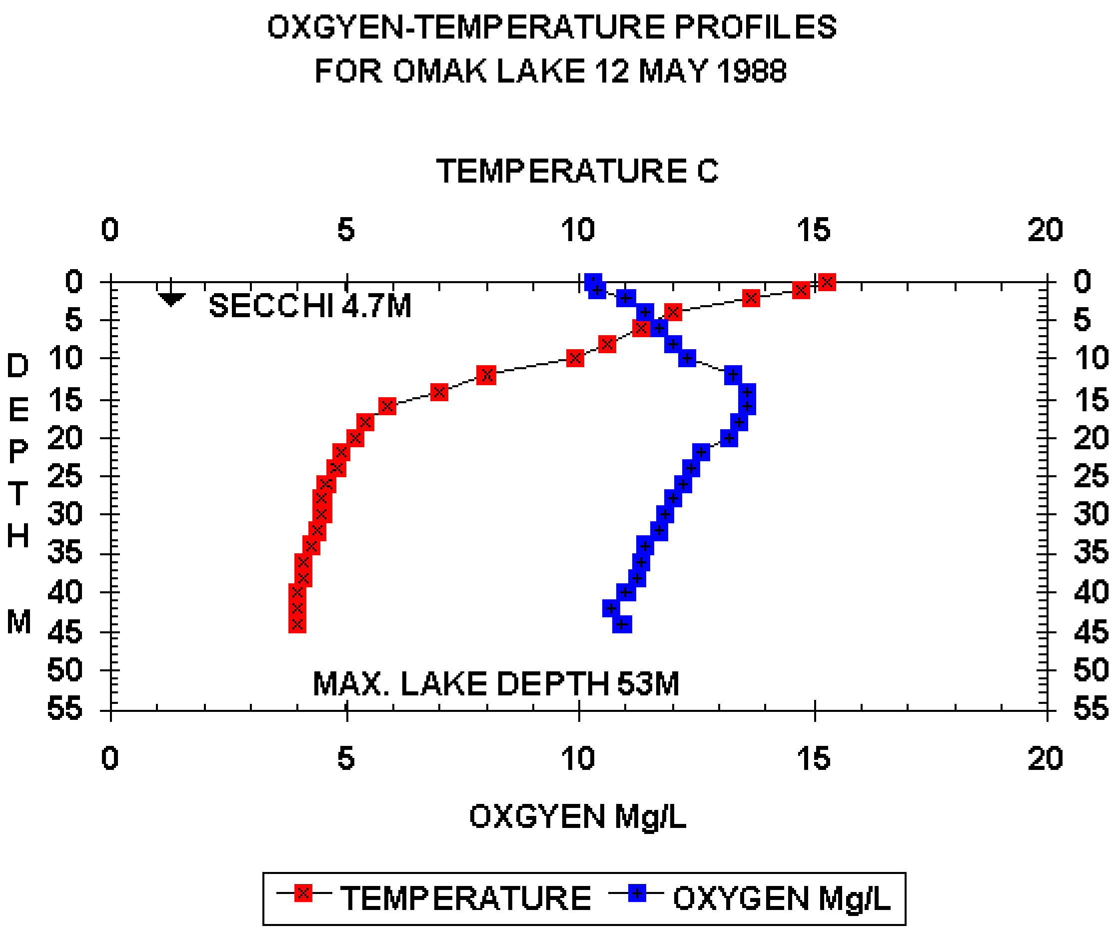
OMAK LAKE NUTRIENT, PRIMARY PRODUCTIVITY, AND ALKALINITY DATA FOR 1988											
Site	**Depth m**	**pH**	**Total Alkalinity mg/l**	**Conductivity micromhos/cm**	**NH4-N mg/l**	**NO2 + NO3 mg/l**	**TKN mg/l**	**Total phos. mg/l**	**Ortho. phos. mg/l**	**Chl a micro g/l**	**Pheophytin micro g/l**
Date May 12, 14, 1988											
A	1.0	9.65	1,718	5,688	<0.02	<0.01	0.63	0.021	0.002		
A	8.0	9.65	1,934	5,768	<0.02	<0.01	0.65	0.020	0.002		
A	14.0	9.60	1,805	5,849	<0.02	<0.01	0.66	0.024	0.002		
A	14.0	9.65	1,819	5,851	<0.02	<0.01	0.66	0.026	0.002		
A	54.0	9.60	1,852	5,972	<0.02	<0.01	0.90	0.041	0.002		
A	60.0	9.60	1,870	5,980	<0.02	<0.01	0.84	0.047	0.002		
A	80.0	9.60	1,905	5,997	<0.02	<0.01	0.70	0.040	0.002		
B	1.0	9.65	1,805	5,554	<0.02	<0.01	0.62	0.020	0.002		
B	8.0	9.65	1,928	5,698	<0.02	<0.01	0.73				
B	14.0	9.60	1,840	5,921	<0.02	<0.01	0.69	0.044	0.002		
B	60.0	9.60	1,870	6,024	<0.02	<0.01	0.68	0.032	0.002		
B	80.0	9.70	1,980	6,244	<0.02	<0.01	0.82	0.035	0.001		
C	1.0	9.65	1,893	5,759	<0.02	<0.01	0.64	0.021	0.002		
C	8.0	9.65	1,975	5,801	<0.02	<0.01	0.63	0.020	0.003		

C	14.0	9.60	1,840	5,834	<0.02	<0.01	0.61	0.020	0.002			
C	60.0	9.60	1,805	5,617	<0.02	<0.01	0.68	0.027	0.002			
C	80.0	9.60	1,910	5,968	<0.02	<0.01	0.66	0.020	0.002			
D	1.0	9.65	1,852	5,401	<0.002	<0.01	0.73	0.026	0.002			
D	8.0	9.70	1,870	5,347	<0.02	<0.01	0.92	0.031	0.002			
D	14.0	9.70	1,881	5,800	<0.02	<0.01	0.56	0.015	0.002			
D	60.0	9.70	1,890	5,837	<0.02	<0.01	0.60	0.028	<0.001			
Omak N. Bay Surf		9.60	1,875	5,870	<0.02	<0.01	0.68	0.024	0.002			
Katar Creek		8.40	161	319	0.04	0.66	0.36	0.030	0.088			
Beaverhouse Creek		8.00	40	101	0.03	0.01	0.46	0.142	0.031			
No Name Creek		8.05	32	101	0.02	<0.01	0.37	0.096	0.030			
Date September 27, 1988												
A	1.0	9.60	1,700	6,045	<0.02	<0.01	0.64	0.014	0.003			
A	8.0	9.60	1,730	6,047	<0.02	<0.01	0.66	0.013	0.003			
A	14.0	9.60	1,530	6,046	<0.02	<0.01	0.64	0.014	0.003			
A	54.0	9.50		5,895	<0.02	<0.01	0.80	0.075	0.012			
B	1.0	9.60	1,720	5,976	<0.02	<0.01	0.66	0.016	0.003			
B	8.0	9.60	1,530	5,962	<0.02	<0.01	0.66	0.020	0.003			

B	14.0	9.60	1,690	5,962	<0.02	<0.01	0.66	0.019	0.003		
B	53.0	9.50	1,560	5,918	0.02	0.01	0.78	0.032	0.004		
D	1.0	9.60	1,600	6,085	<0.02	<0.01	0.72	0.008	0.002		
D	8.0	9.60	1,590	6,085	<0.02	<0.01	0.72	0.008	0.002		
D	14.0	9.60	1,600	6,085	<0.02	<0.01	0.72	0.0008	0.002		
D	54.0	9.70	1,600	6,069	<0.02	<0.01	0.60	0.016	0.003		

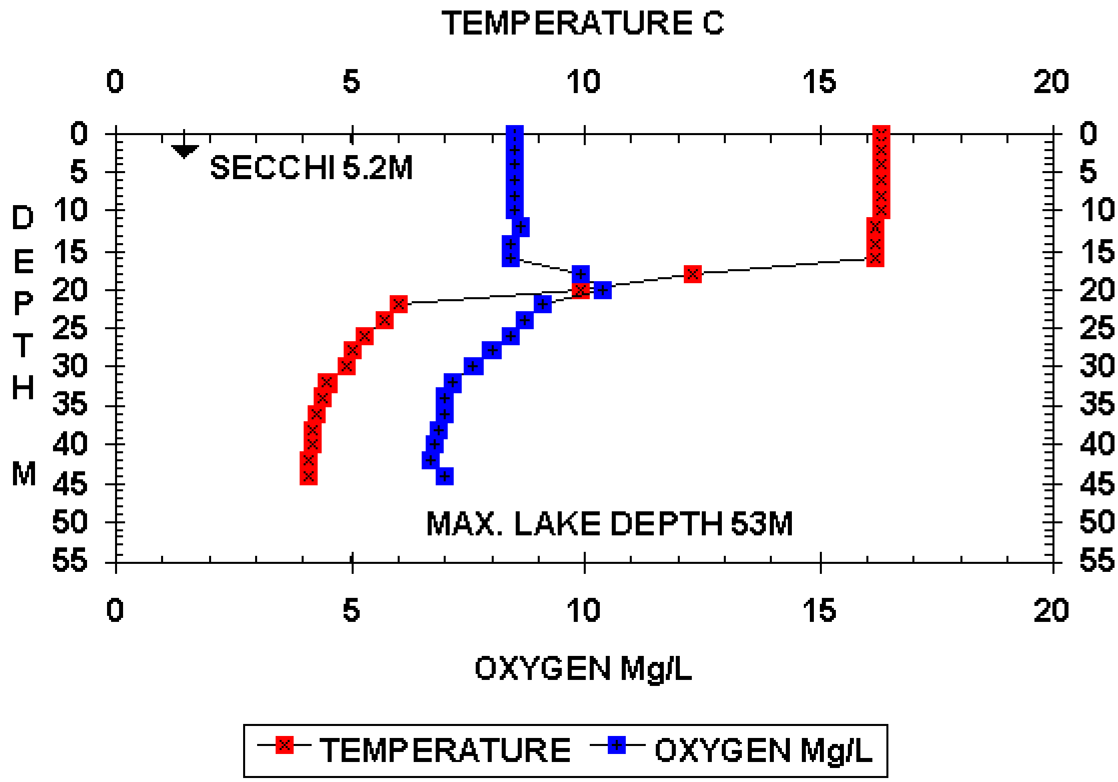
OXYGEN-TEMPERATURE PROFILES FOR OMAK LAKE 1988

Spring 1988



Autumn 1988

OXYGEN-TEMPERATURE PROFILES
FOR OMAK LAKE 27 SEPTEMBER 1988



THE PHYTOPLANKTON OF OMAK LAKE

RESULTS

(See tables below for phytoplankton data)

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May 14, 1988

Algal cell densities were low in all but the 14 m collection (approximately 760 cells/ml) from Station A. The collections from Omak Lake Station A were dominated by centric blue-greens and diatoms. The algae identified in the 1 m collection were *Lyngbya cf. contorta* (43%) and small centric diatoms (42%), large centric diatoms (5%), and *Oocystis sp.* (4%). At 4 m, small centric diatoms (70%) and large centric diatoms (10%) were dominant. Small centric diatoms composed 97% of the population at 8 m and 87% at 14 m.

September 27, 1988

Phytoplankton cell densities were low (to 100 cells/ml) in collections from Station A (1 m and 8 m) and the 1 m and 4 m samples from Station D. Density at 8 m at Station D was 3600 cells/m and ranged from 4700 to 6600 cells/ml in collections from Station B. The dominant alga in collections from 1 m at stations A, B, and D was the *filamentous blue-green Lyngbya*. At Station A, L. contorta composed 87% of the cells counted in the 1 m collection and 92% at 8 m. At Station B, L. contorta (74% at 1 m, 70% at 4 m, 65% at 8 m) and Lyngbya sp. (16% at 1 m, 30% at 4 m, 27% at 8 m) were also strongly represented. Except for the filamentous blue-green *Oscillatoria sp*. (10% at 1 m and 8% at 8 m), the associated algae accounted for <1% of the cell counts in the Station B samples. At Station D, Lyngbya sp. composed 32% of the cells counted at 1 m and 83% at 8 m. Other blue-green well represented at Station D were *Anabaena sp.* 1 (20% at 1 m, 23% at 4 m), *Anabaena, sp.* (38% at 4m), *Anabaena cf. torulosa* (16% at 1 m), *Oscillatoria* (15% at 8 m), *Chroococcus* (23% at 4 m). The green alga *Oocystis sp.* composed 16% of the count at 1 m and 11% at 4 m.

Discussion

The most abundant algae in the May, 1988, collections from Omak Lake were the filamentous blue-green *Lyngbya* and centric diatoms. In the September collections *Lyngbya contorta*, *Anabaena sp.* and *Oscillatoria sp.* were the abundant algae.

***Anabaena* is frequently abundant in eutrophic lakes in early to mid-summer (Hutchinson 1967; Taylor, et al. 1981) and *Lyngbya* and *Oocystis* are typical of eutrophic waters (Taylor, et al. 1981). Although some species of *Oscillatoria* are found in oligotrophic lakes, others are common in mesotrophic to eutrophic lakes, ponds and stagnant waters (Paerl 1988). *Chroococcus* is commonly a subdominant in mesotrophic and eutrophic lakes, ponds and rivers (Paerl 1988). Gloeocystis is most frequently found in ponds and shallow, fertile lakes (Hutchinson 1967).**

The presence of moderate numbers of phytoplankton typical of mesotrophic to eutrophic waters in the May and September, 1988, collections from Omak Lake indicates that nutrient availability is moderate.

Literature Cited

OMAK LAKE PHYTOPLANKTON FOR SPRING AND AUTUMN 1988

Spring, 14 May 1988

Sample Depth	Phytoplankton	Algal Cells per ml	Percentage
1 M<ETER< TH>	*Lyngbya cf. contorta*	40	43%
	small centric diatoms	39	42%
	large centric diatoms	5	5%
	Oocystis sp.	4	4%
	Ankistrodesmus sp.	2	2%

	Lagerheimia wratislavensis	2	2%
4 Meter	small centric diatoms	107	70%
	large centric diatoms	15	10%
	erismopedia tenuissima Lemm.	8	5%
	Lyngbya cf. contorta	6	4%
	Rhodomonas sp.	5	3%
	Oocystis sp.	3	2%
	Ankistrodesmus falcatus var. mirabilis	3	2%
8 Meter	small centric diatoms	165	97%
	Oocystis cf. pusilla	4	2%
14 Meter	small centric diatoms	666	87%
	large centric diatoms	99	13%
	Scenedesmus sp.	2	2%
Autumn 27, September 1988			
Station A			
Sample Depth	**Phytoplankton**	**Algal Cells per ml**	**Percentage**
1 Meter	*Lyngbya contorta*	75	87%
	Chlamydomonas sp.	3	3%
	Anabaena sp.	2	2%
	Chroococcus varius	2	2%
	Gloeocystis planktonica Lemm.	2	2%
8 Meter	*Lyngbya contorta*	100	92%
	Oocystis cf. pusilla	2	2%
	Chroococcus varius	2	2%
Station B			
Sample Depth	**Phytoplankton**	**Algal Cells per**	**Percentage**

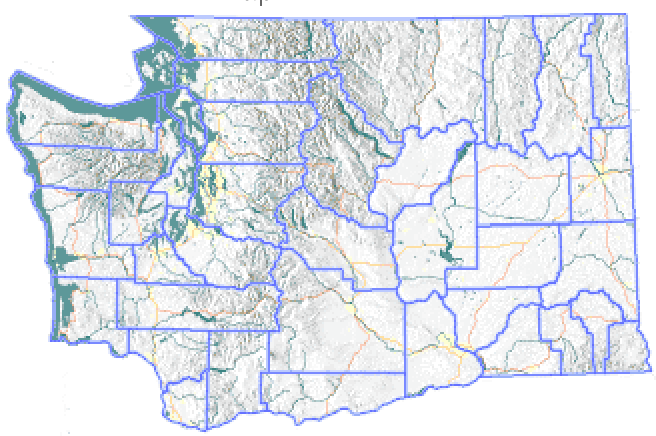
		ml	
1 Meters	*Lyngbya contorta*	4500	74%
	Lyngbya sp.	940	16%
	Oscillatoria sp.	600	10%
4 Meter	*Lyngbya contorta*	3300	70%
	Lyngbya sp.	1400	30%
	unidentified blue-green alga	15	1%
8 Meters	*Lyngbya contorta*	4300	65%
	Lyngbya sp.	1800	27%
	Oscillatoria sp.	550	8%

Station D			
Sample Depth	**Phytoplankton**	**Algal Cells per ml**	**Percentage**
1 Meter	*Lyngbya sp.*	17	32%
	Anabaena sp.	11	20%
	Oocystis cf. submarina	9	16%
	Anabaena cf. torulosa	8	16%
	Lagerheimia subsalsa	1	3%
	Scenedesmus bijuga	1	3%
	Gloeocystis planctonica	1	3%
	unidentified spherical flagellates	1	3%
	Ankistrodesmus falcatus	1	2%
	small centric diatoms	1	2%
4 Meter	*Anabaena sp.*	30	38%
	Anabaena sp.	16	23%
	Chroococcus dispersus	6	23%
	Oocystis sp.	3	11%
	Chroomonas acuta	1	4%

	small centric diatom	1	3%
8 Meters	*Lyngbya contorta*	3100	83%
	Oscillatoria sp.	550	15%
	Chroococcus dispersus	8	2%

Omak Lake

County	Okanogan
Latitude	48.3225
Longitude	119.4289
Ecoregion	Columbia Basin
years surveyed	1996
map link	



Species

scientific name	common name
Amphiscirpus nevadensis	Nevada bulrush
Chara sp.	muskwort
Ruppia cirrhosa	ditch-grass
Schoenoplectus americanus	American bulrush
Scirpus sp.	bulrush
Typha sp.	cat-tail

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Amphiscirpus nevadensis	8/28/1996	2	Ecology	sandy soil, shallow water
Chara sp.	8/28/1996	2	"	short compact plants
Ruppia cirrhosa	8/28/1996	2	"	blooming
Schoenoplectus americanus	8/28/1996	2	"	wetland area at inflow

Scirpus sp.	8/28/1996	1	"	in freshwater inflow
Typha sp.	8/28/1996	1	"	in freshwater inflow

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
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D	8.0	9.70	1,870	5,347	<0.02	<0.01	0.92	0.031	0.002		
D	14.0	9.70	1,881	5,800	<0.02	<0.01	0.56	0.015	0.002		
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B	14.0	9.60	1,690	5,962	<0.02	<0.01	0.66	0.019	0.003		
B	53.0	9.50	1,560	5,918	0.02	0.01	0.78	0.032	0.004		
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D	14.0	9.60	1,600	6,085	<0.02	<0.01	0.72	0.0008	0.002		
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THE PHYTOPLANKTON OF OMAK LAKE

RESULTS

(See tables below for phytoplankton data)

.

May 14, 1988

Algal cell densities were low in all but the 14 m collection (approximately 760 cells/ml) from Station A. The collections from Omak Lake Station A were dominated by centric blue-greens and diatoms. The algae identified in the 1 m collection were *Lyngbya cf. contorta* (43%) and small centric diatoms (42%), large centric diatoms (5%), and *Oocystis sp.* (4%). At 4 m, small centric diatoms (70%) and large centric diatoms (10%) were dominant. Small centric diatoms composed 97% of the population at 8 m and 87% at 14 m.

September 27, 1988

Phytoplankton cell densities were low (to 100 cells/ml) in collections from Station A (1 m and 8 m) and the 1 m and 4 m samples from Station D. Density at 8 m at Station D was 3600 cells/m and ranged from 4700 to 6600 cells/ml in collections from Station B. The dominant alga in collections from 1 m at stations A, B, and D was the *filamentous blue-green Lyngbya*. At Station A, L. contorta composed 87% of the cells counted in the 1 m collection and 92% at 8 m. At Station B, L. contorta (74% at 1 m, 70% at 4 m, 65% at 8 m) and Lyngbya sp. (16% at 1 m, 30% at 4 m, 27% at 8 m) were also strongly represented. Except for the filamentous blue-green *Oscillatoria sp*. (10% at 1 m and 8% at 8 m), the associated algae accounted for <1% of the cell counts in the Station B samples. At Station D, Lyngbya sp. composed 32% of the cells counted at 1 m and 83% at 8 m. Other blue-green well represented at Station D were *Anabaena sp.* 1 (20% at 1 m, 23% at 4 m), *Anabaena, sp.* (38% at 4m), *Anabaena cf. torulosa* (16% at 1 m), *Oscillatoria* (15% at 8 m), *Chroococcus* (23% at 4 m). The green alga *Oocystis sp.* composed 16% of the count at 1 m and 11% at 4 m.

Discussion

The most abundant algae in the May, 1988, collections from Omak Lake were the filamentous blue-green *Lyngbya* and centric diatoms. In the September collections *Lyngbya contorta, Anabaena sp.* and *Oscillatoria sp.* were the abundant algae.

***Anabaena* is frequently abundant in eutrophic lakes in early to mid-summer (Hutchinson 1967; Taylor, et al. 1981) and *Lyngbya* and *Oocystis* are typical of eutrophic waters (Taylor, et al. 1981). Although some species of *Oscillatoria* are found in oligotrophic lakes, others are common in mesotrophic to eutrophic lakes, ponds and stagnant waters (Paerl 1988). *Chroococcus* is commonly a subdominant in mesotrophic and eutrophic lakes, ponds and rivers (Paerl 1988). Gloeocystis is most frequently found in ponds and shallow, fertile lakes (Hutchinson 1967).**

The presence of moderate numbers of phytoplankton typical of mesotrophic to eutrophic waters in the May and September, 1988, collections from Omak Lake indicates that nutrient availability is moderate.

Literature Cited

OMAK LAKE PHYTOPLANKTON FOR SPRING AND AUTUMN 1988

Spring, 14 May 1988			
Sample Depth	**Phytoplankton**	**Algal Cells per ml**	**Percentage**
1 M<ETER< TH>	*Lyngbya cf. contorta*	40	43%
	small centric diatoms	39	42%
	large centric diatoms	5	5%
	Oocystis sp.	4	4%
	Ankistrodesmus sp.	2	2%
	Lagerheimia wratislavensis	2	2%
4 Meter	small centric diatoms	107	70%
	large centric diatoms	15	10%
	erismopedia tenuissima Lemm.	8	5%
	Lyngbya cf. contorta	6	4%
	Rhodomonas sp.	5	3%
	Oocystis sp.	3	2%
	Ankistrodesmus falcatus var. mirabilis	3	2%
8 Meter	small centric diatoms	165	97%
	Oocystis cf. pusilla	4	2%
14 Meter	small centric diatoms	666	87%
	large centric diatoms	99	13%
	Scenedesmus sp.	2	2%

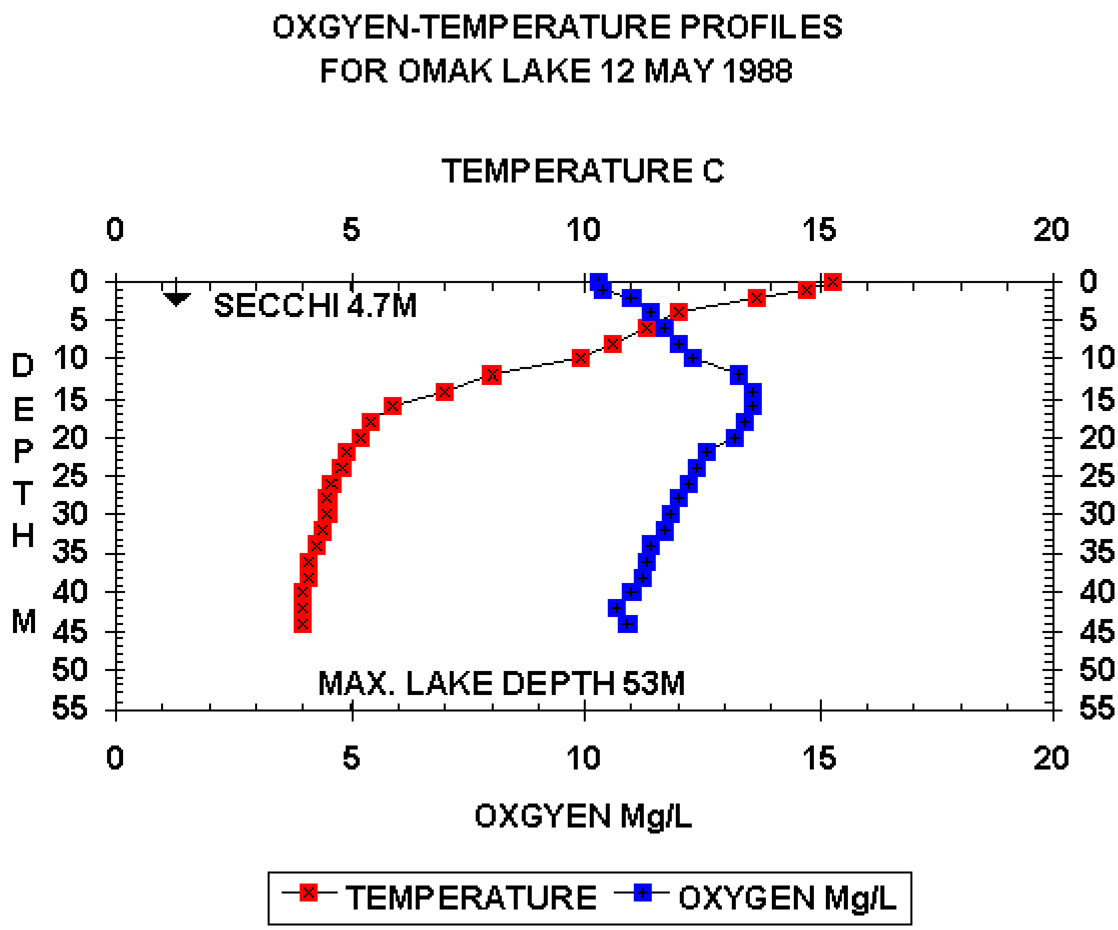
Autumn 27, September 1988			
Station A			
Sample Depth	**Phytoplankton**	**Algal Cells per ml**	**Percentage**

1 Meter	*Lyngbya contorta*	75	87%
	Chlamydomonas sp.	3	3%
	Anabaena sp.	2	2%
	Chroococcus varius	2	2%
	Gloeocystis planktonica Lemm.	2	2%
8 Meter	*Lyngbya contorta*	100	92%
	Oocystis cf. pusilla	2	2%
	Chroococcus varius	2	2%
Station B			
Sample Depth	**Phytoplankton**	**Algal Cells per ml**	**Percentage**
1 Meters	*Lyngbya contorta*	4500	74%
	Lyngbya sp.	940	16%
	Oscillatoria sp.	600	10%
4 Meter	*Lyngbya contorta*	3300	70%
	Lyngbya sp.	1400	30%
	unidentified blue-green alga	15	1%
8 Meters	*Lyngbya contorta*	4300	65%
	Lyngbya sp.	1800	27%
	Oscillatoria sp.	550	8%
Station D			
Sample Depth	**Phytoplankton**	**Algal Cells per ml**	**Percentage**
1 Meter	*Lyngbya sp.*	17	32%
	Anabaena sp.	11	20%
	Oocystis cf. submarina	9	16%
	Anabaena cf. torulosa	8	16%
	Lagerheimia subsalsa	1	3%

	Scenedesmus bijuga	1	3%
	Gloeocystis planctonica	1	3%
	unidentified spherical flagellates	1	3%
	Ankistrodesmus falcatus	1	2%
	small centric diatoms	1	2%
4 Meter	*Anabaena sp.*	30	38%
	Anabaena sp.	16	23%
	Chroococcus dispersus	6	23%
	Oocystis sp.	3	11%
	Chroomonas acuta	1	4%
	small centric diatom	1	3%
8 Meters	*Lyngbya contorta*	3100	83%
	Oscillatoria sp.	550	15%
	Chroococcus dispersus	8	2%

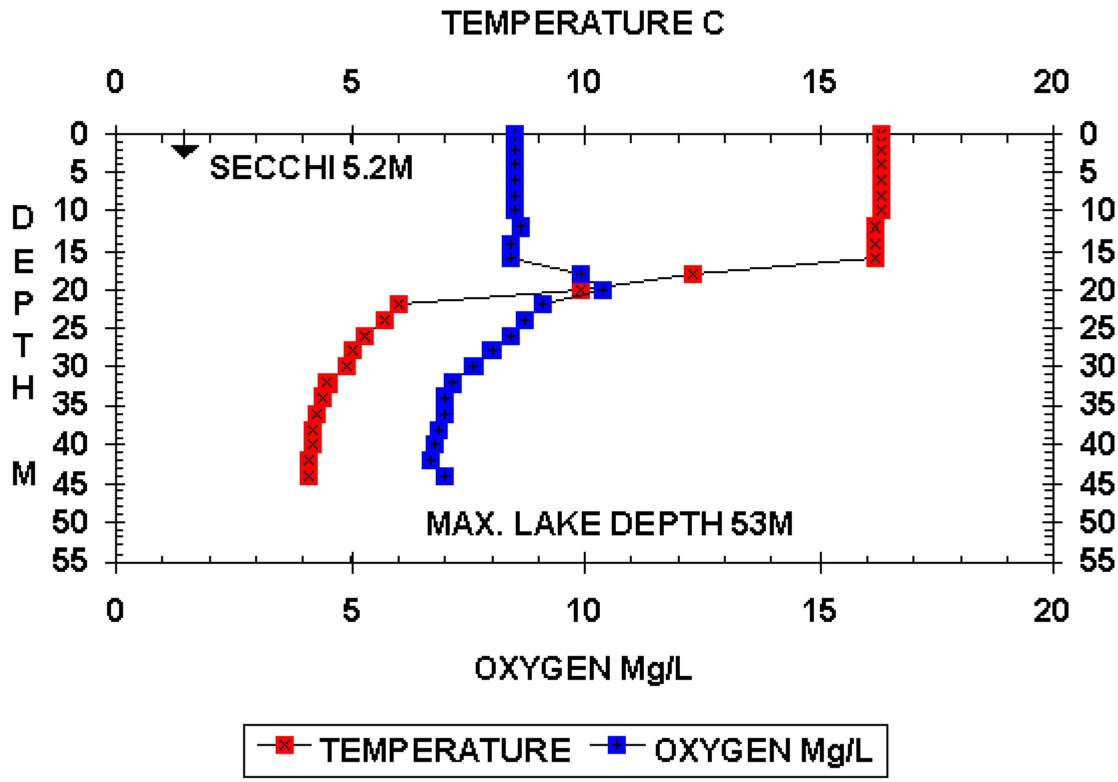
OXYGEN-TEMPERATURE PROFILES FOR OMAK LAKE 1988

Spring 1988



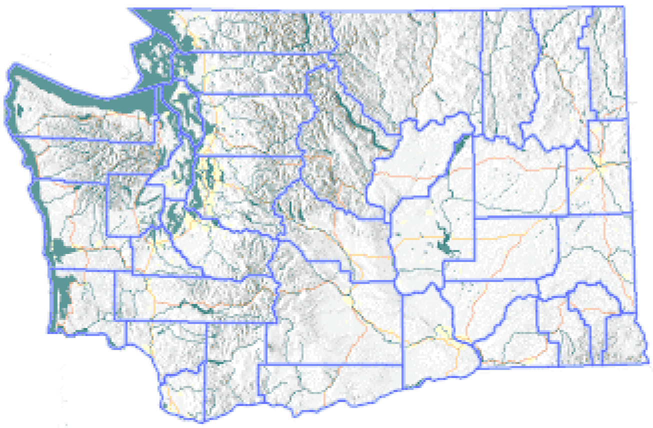
Autumn 1988

OXYGEN-TEMPERATURE PROFILES
FOR OMAK LAKE 27 SEPTEMBER 1988



Alta Lake

County	Okanogan
Latitude	48.01167
Longitude	119.9386
Ecoregion	Columbia Basin
years surveyed	2007, 1995
map link	



Species

scientific name	common name
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Juncus sp.	rush
Myriophyllum sibiricum	northern watermilfoil
Polygonum amphibium	water smartweed
Polygonum hydropiperoides	common smartweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton pusillus	slender pondweed
Rorippa sp.	cress
Rumex sp.	dock
Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Stuckenia pectinata	sago pondweed
Typha latifolia	common cat-tail
Zannichellia palustris	horned pondweed

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Carex sp.	8/23/2007		Ecology	several species on protected shoreline
Ceratophyllum demersum	6/29/1995	1	"	
"	8/23/2007	1	"	
Chara sp.	6/29/1995	4	"	meadow on bottom
"	8/23/2007	4	"	thick mat
Juncus sp.	8/23/2007		"	several species on protected shoreline
Myriophyllum sibiricum	6/29/1995	3	"	some thick patches
"	8/23/2007	3	"	no flowers
Polygonum amphibium	6/29/1995	2	"	
"	8/23/2007	1	"	west side of lake
Polygonum hydropiperoides	8/23/2007	1	"	at boatlaunch
Potamogeton illinoensis	8/23/2007	2	"	patches scattered over whole lake
Potamogeton pusillus	6/29/1995	2	"	
Rorippa sp.	6/29/1995	2	"	shallows, south end
Rumex sp.	6/29/1995	2	"	emergent, south end
Schoenoplectus sp.	8/23/2007	3	"	
Scirpus sp.	6/29/1995	2	"	
Stuckenia pectinata	6/29/1995	2	"	
"	8/23/2007	3	"	dense in some shallow areas
Typha latifolia	8/23/2007	2	"	
Zannichellia palustris	6/29/1995	2	"	

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
2. "Source" is the organization that provided the data. "Ecology" refers to the Washington State Department of Ecology.

Washington State Department of Ecology

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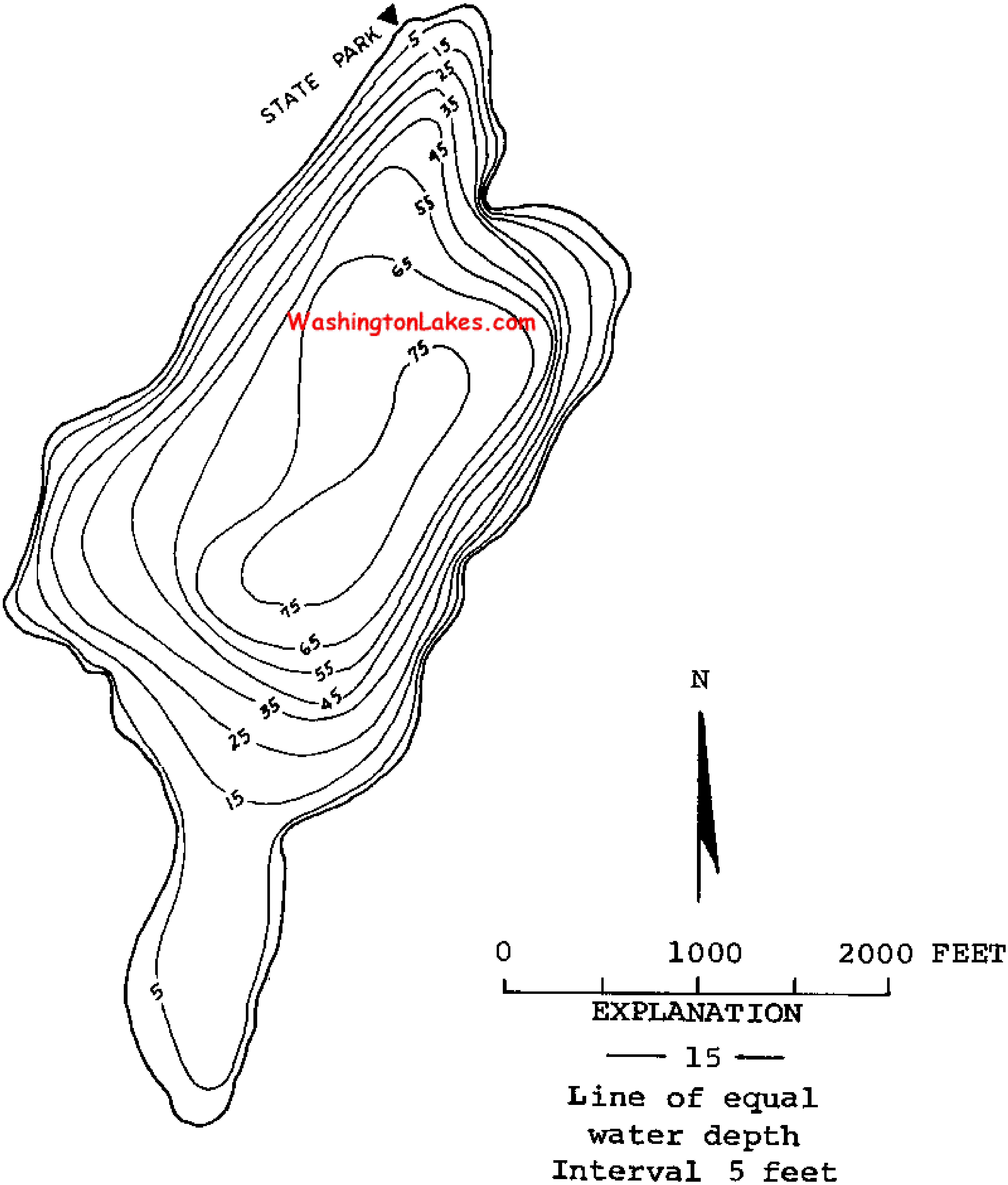

Alta Lake, Okanogan County. From Washington Department of Game, January 3, 1950.

Department of Ecology Aquatic Plant Monitoring

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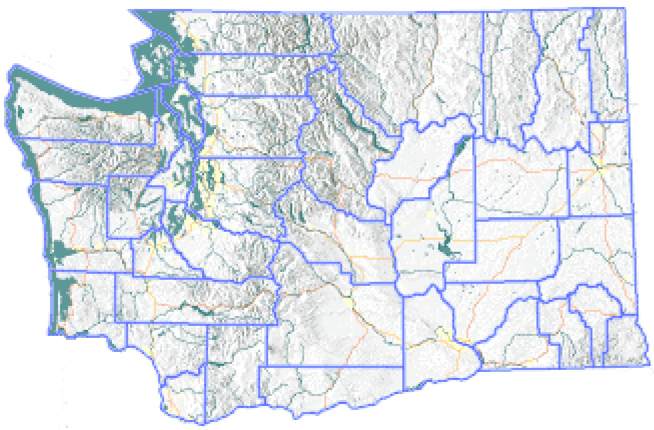
Blue Lake (37N-25E-22)

County	Okanogan
Latitude	48.69222
Longitude	119.6892
Ecoregion	Columbia Basin
years surveyed	2007, 1999
map link	



Species

scientific name	common name
Callitriche hermaphroditica	northern water-starwort
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Elodea sp.	waterweed
Fontinalis antipyretica	water moss
Lemna trisulca	star duckweed
Myriophyllum sibiricum	northern watermilfoil
Nitella sp.	stonewort
Phalaris arundinacia	reed canarygrass
Polygonum amphibium	water smartweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton sp.	pondweed
Ranunculus aquatilis	water-buttercup

Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Stuckenia filiformis	slender leaved pondweed
unknown plant	unknown
unknown plant 2	unknown

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Callitriche hermaphroditica	6/21/2007		Ecology	IDed by leaf characteristics
Ceratophyllum demersum	7/14/1999	2	"	
"	6/21/2007	3	"	some dense growth in north end
Chara sp.	7/14/1999	3	"	meadows in small south basin
"	6/21/2007	3	"	
Eleocharis sp.	7/14/1999	2	"	
"	6/21/2007	3	"	
Elodea canadensis	7/14/1999	2	"	
Elodea sp.	6/21/2007	2	"	
Fontinalis antipyretica	7/14/1999	1	"	deep
"	6/21/2007	1	"	
Lemna trisulca	7/14/1999	2	"	
Myriophyllum sibiricum	7/14/1999	2	"	
"	6/21/2007	1	"	
Nitella sp.	7/14/1999	1	"	
"	6/21/2007	1	"	
Phalaris arundinacia	6/21/2007	3	"	some growing like a lawn underwater
Polygonum amphibium	7/14/1999	2	"	
"	6/21/2007	2	"	
Potamogeton gramineus	7/14/1999	1	"	
Potamogeton illinoensis	7/14/1999	3	"	dominant submersed plant
"	6/21/2007	3	"	some submersed leaves sessile
Potamogeton sp (thin leaved)	7/14/1999	2	"	more dense on east shore
Potamogeton sp.	6/21/2007	1	"	
Ranunculus aquatilis	7/14/1999	1	"	
"	6/21/2007	2	"	
Schoenoplectus sp.	6/21/2007	2	"	bulrush
Scirpus sp.	7/14/1999	1	"	bulrush
Stuckenia filiformis	6/21/2007	2	"	subspecies occidentalis
unknown plant	7/14/1999	2	"	Potamogeton vaginatus? Sample collected
unknown plant 2	7/14/1999	1	"	long leaves floating on surface like a

				sparganium, but not all basal

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Washington State Department of Ecology

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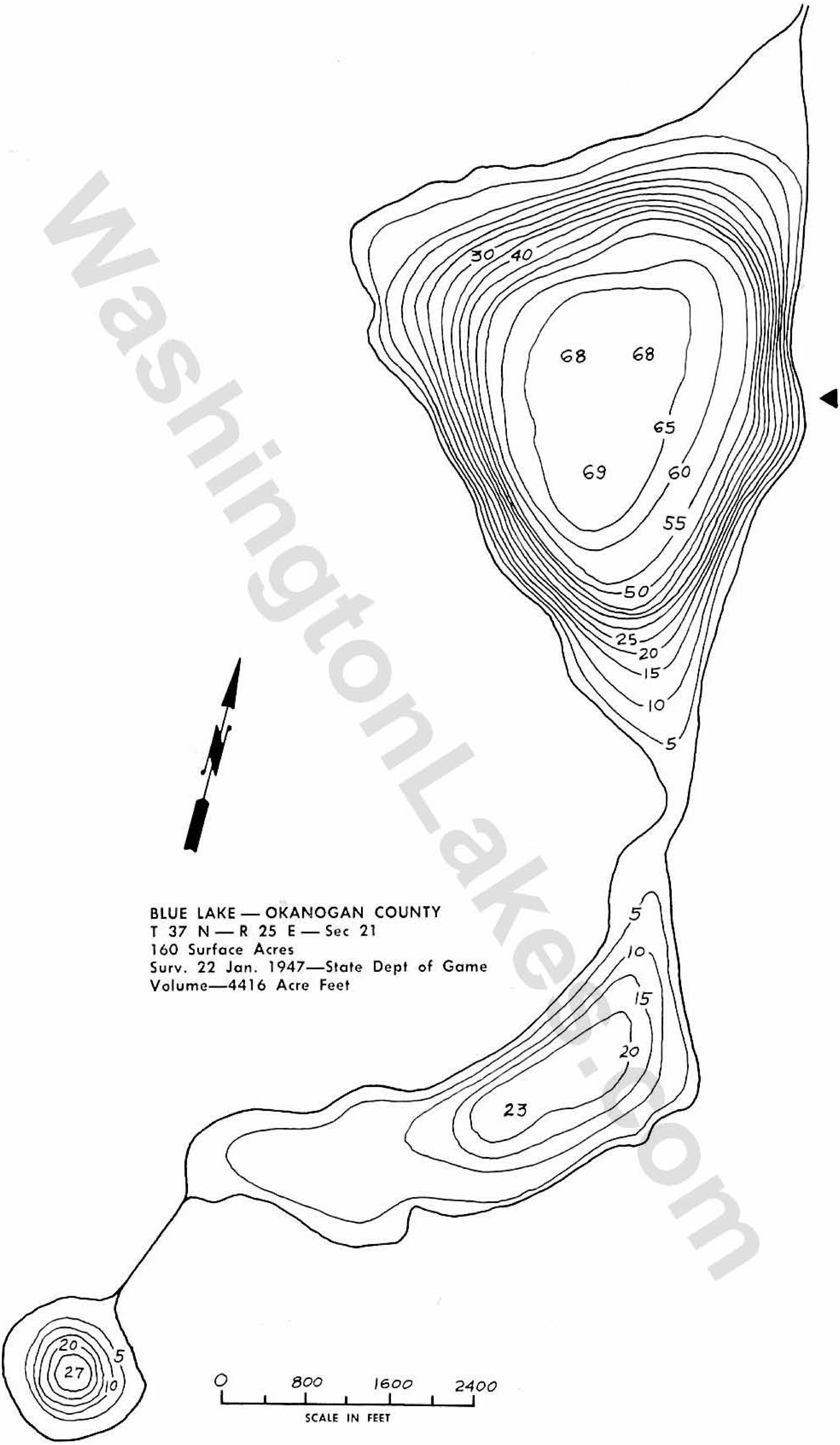
30
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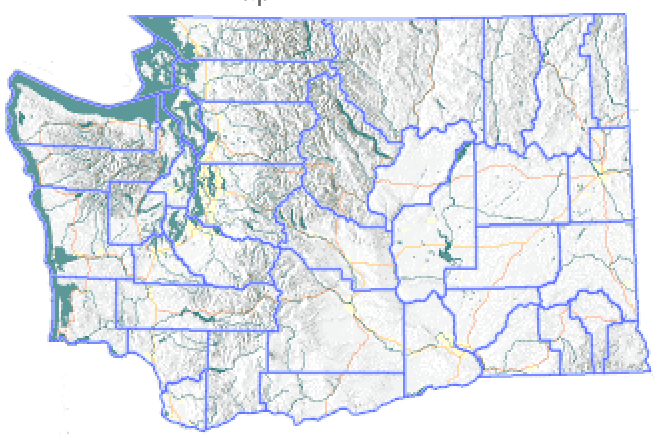
800
1600
2400
SCALE IN FEET
BLUE LAKE — OKANOGAN COUNTY
T 37 N — R 25 E — Sec 21
160 Surface Acres
Surv. 22 Jan. 1947—State Dept of Game
Volume—4416 Acre Feet

Buffalo Lake

County	Okanogan
Latitude	48.0625
Longitude	118.8917
Ecoregion	Columbia Basin
years surveyed	2008, 1995
map link	



Species

scientific name	common name
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Juncus sp.	rush
Myriophyllum sibiricum	northern watermilfoil
Polygonum amphibium	water smartweed
Potamogeton richardsonii	Richardson's pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton zosteriformis	eel-grass pondweed
Stuckenia pectinata	sago pondweed

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Eleocharis sp.	8/21/1995	2	Ecology	

Elodea canadensis	8/21/1995	2	"	
Juncus sp.	8/21/1995	2	"	
Myriophyllum sibiricum	8/21/1995	3	"	forming mats at south end
"	8/20/2008	1	"	the only submersed plant seen, very little growth (only looked from shore)
Polygonum amphibium	8/21/1995	1	"	
Potamogeton richardsonii	8/21/1995	2	"	
Potamogeton sp (thin leaved)	8/21/1995	2	"	
Potamogeton zosteriformis	8/21/1995	2	"	
Stuckenia pectinata	8/21/1995	2	"	

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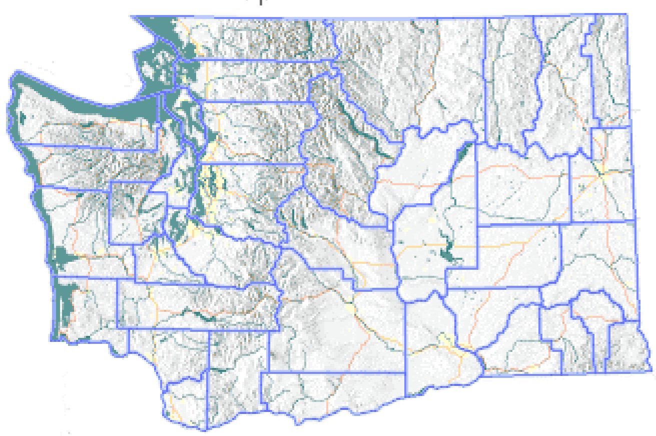
Chopaka Lake

County	Okanogan
Latitude	48.90361
Longitude	119.6925
Ecoregion	Cascades
years surveyed	1999
map link	



Species

scientific name	common name
Chara sp.	muskwort
Fontinalis antipyretica	water moss
Hippuris vulgaris	common marestail
Iris pseudacorus	yellow flag
Ruppia cirrhosa	ditch-grass
Scirpus sp.	bulrush
Stuckenia pectinata	sago pondweed
Utricularia vulgaris	common bladderwort

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Chara sp.	7/13/1999	3	Ecology	
Fontinalis antipyretica	7/13/1999	2	"	in deeper water
Hippuris vulgaris	7/13/1999	1	"	one patch near campground
Iris pseudacorus	7/13/1999	1	"	
Ruppia cirrhosa	7/13/1999	3	"	
Scirpus sp.	7/13/1999	2	"	rings shallows
Stuckenia pectinata	7/13/1999	1	"	along west shore
Utricularia vulgaris	7/13/1999	1	"	two plants found floating

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
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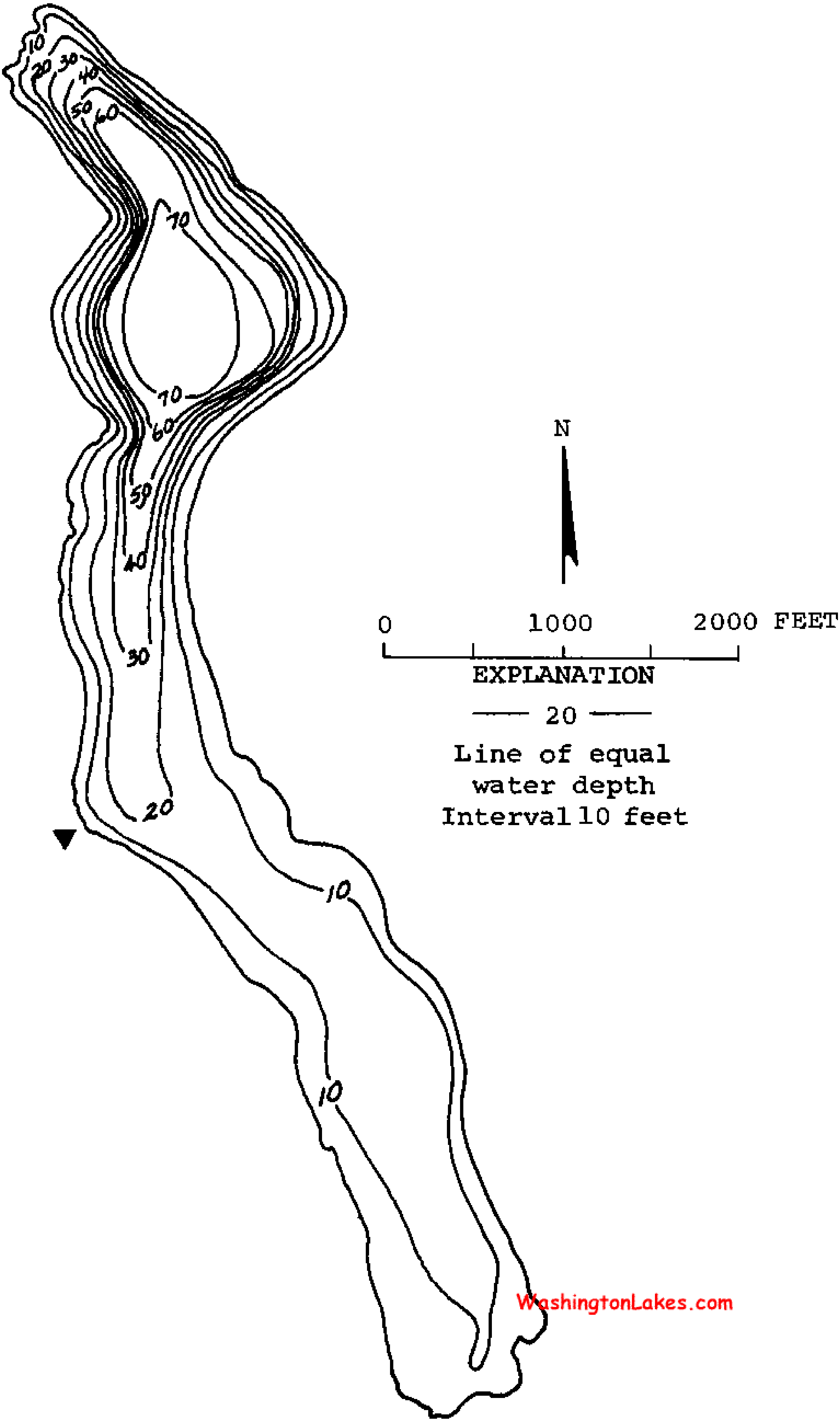

Chopaka Lake, Okanogan County. From
U.S. Geological Survey, August 13, 1974.

Department of Ecology Aquatic Plant Monitoring

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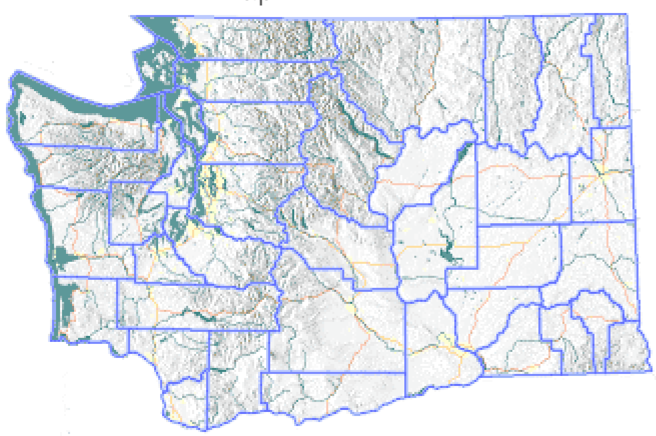
Connors Lake

County	Okanogan
Latitude	48.75083
Longitude	119.6583
Ecoregion	Columbia Basin
years surveyed	2007
map link	



Species

scientific name	common name
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Elodea sp.	waterweed
Lemna sp.	duckweed
Myriophyllum sibiricum	northern watermilfoil
Polygonum sp.	smartweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton natans	floating leaf pondweed
Potamogeton obtusifolius	bluntleaf pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Schoenoplectus sp.	naked-stemmed bulrush
Stuckenia pectinata	sago pondweed
Typha latifolia	common cat-tail

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Carex sp.	6/20/2007	1	Ecology	two species, C. retrorsa and C. rostrata
Ceratophyllum demersum	6/20/2007	4	"	dominant submersed species
Chara sp.	6/20/2007	3	"	
Elodea sp.	6/20/2007	3	"	
Lemna sp.	6/20/2007	2	"	
Myriophyllum sibiricum	6/20/2007	3	"	most around edge of lake
Polygonum sp.	6/20/2007	1	"	
Potamogeton illinoensis	6/20/2007		"	in sample, leaves sessile
Potamogeton natans	6/20/2007	3	"	
Potamogeton obtusifolius	6/20/2007		"	
Potamogeton sp (thin leaved)	6/20/2007	3	"	
Schoenoplectus sp.	6/20/2007	2	"	bulrush
Stuckenia pectinata	6/20/2007	3	"	
Typha latifolia	6/20/2007	3	"	

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Washington State Department of Ecology

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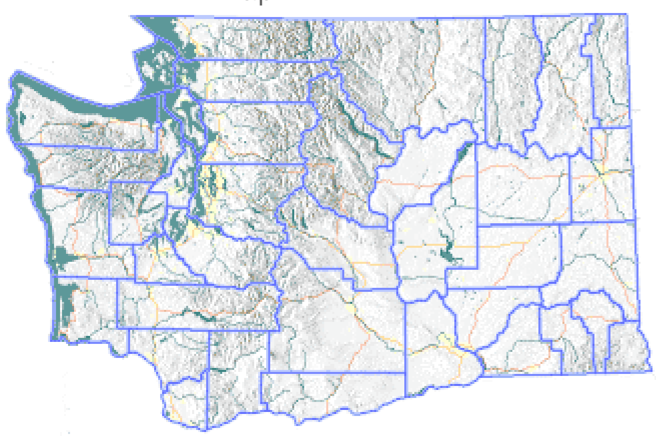
Conconully Reservoir (35N-25E-18)

County	Okanogan
Latitude	48.53778
Longitude	119.7472
Ecoregion	Columbia Basin
years surveyed	2012, 1997, 1994
map link	



Species

scientific name	common name
Callitriche hermaphroditica	northern water-starwort
Chara sp.	muskwort
Elatine sp.	waterwort
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Elodea nuttallii	Nuttall's waterweed
Equisetum sp.	horse tail
Hippuris vulgaris	common marestail
Juncus sp.	rush
Juncus sp. or Eleocharis sp.	small grass-like plants
Limosella aquatica	mudwort
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum sp.	water-milfoil
Myriophyllum spicatum	Eurasian water-milfoil
Nitella sp.	stonewort
Polygonum amphibium	water smartweed
Potamogeton crispus	curly leaf pondweed

Potamogeton gramineus	grass-leaved pondweed
Potamogeton pusillus	slender pondweed
Potamogeton richardsonii	Richardson's pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Ranunculus aquatilis	water-buttercup
Salix sp.	willow
Stuckenia pectinata	sago pondweed
unknown plant	unknown

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Callitriche hermaphroditica	7/26/1994	2	Ecology	
"	9/18/1997	2	"	south end of lake, near Shady Pines Resort
Chara sp.	7/26/1994	2	"	
Elatine sp.	9/18/1997	1	"	
Eleocharis sp.	7/26/1994	2	"	
"	7/4/2012	2	"	
Elodea canadensis	7/4/2012	2	"	
Elodea nuttallii	7/26/1994	2	"	
"	9/18/1997	2	"	long, narrow leaves
"	7/4/2012	2	"	
Equisetum sp.	7/26/1994	3	"	
"	9/18/1997	2	"	
Hippuris vulgaris	7/26/1994	1	"	in shallows
"	9/18/1997	2	"	above water at State Park
Juncus sp.	7/4/2012	2	"	
Juncus sp. or Eleocharis sp.	9/18/1997	2	"	shallows
Limosella aquatica	9/18/1997	1	"	in cove, south end
Myriophyllum sibiricum	9/18/1997	2	"	
Myriophyllum sp.	7/4/2012	2	"	
Myriophyllum spicatum	9/18/1997	2	"	near boat launch area, deeper water
Nitella sp.	9/18/1997	1	"	
Polygonum amphibium	7/26/1994	2	"	on margins
"	9/18/1997	2	"	
"	7/4/2012	3	"	
Potamogeton crispus	7/4/2012	1	"	
Potamogeton gramineus	7/26/1994	3	"	
"	9/18/1997	3	"	
"	7/4/2012	2	"	may be a hybrid with P. illinoensis
Potamogeton pusillus	7/26/1994	2	"	
Potamogeton richardsonii	9/18/1997	2	"	may be a cross with P. praelongus?

Potamogeton sp (thin leaved)	9/18/1997	3	"	
"	7/4/2012	1	"	
Ranunculus aquatilis	7/26/1994	2	"	
"	9/18/1997	3	"	
"	7/4/2012	3	"	
Salix sp.	7/4/2012	3	"	
Stuckenia pectinata	7/26/1994	2	"	
unknown plant	7/26/1994	1	"	opposite leaved submersed plant
"	7/4/2012	1	"	may be Schoenoplectur subterminalis

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Washington State Department of Ecology

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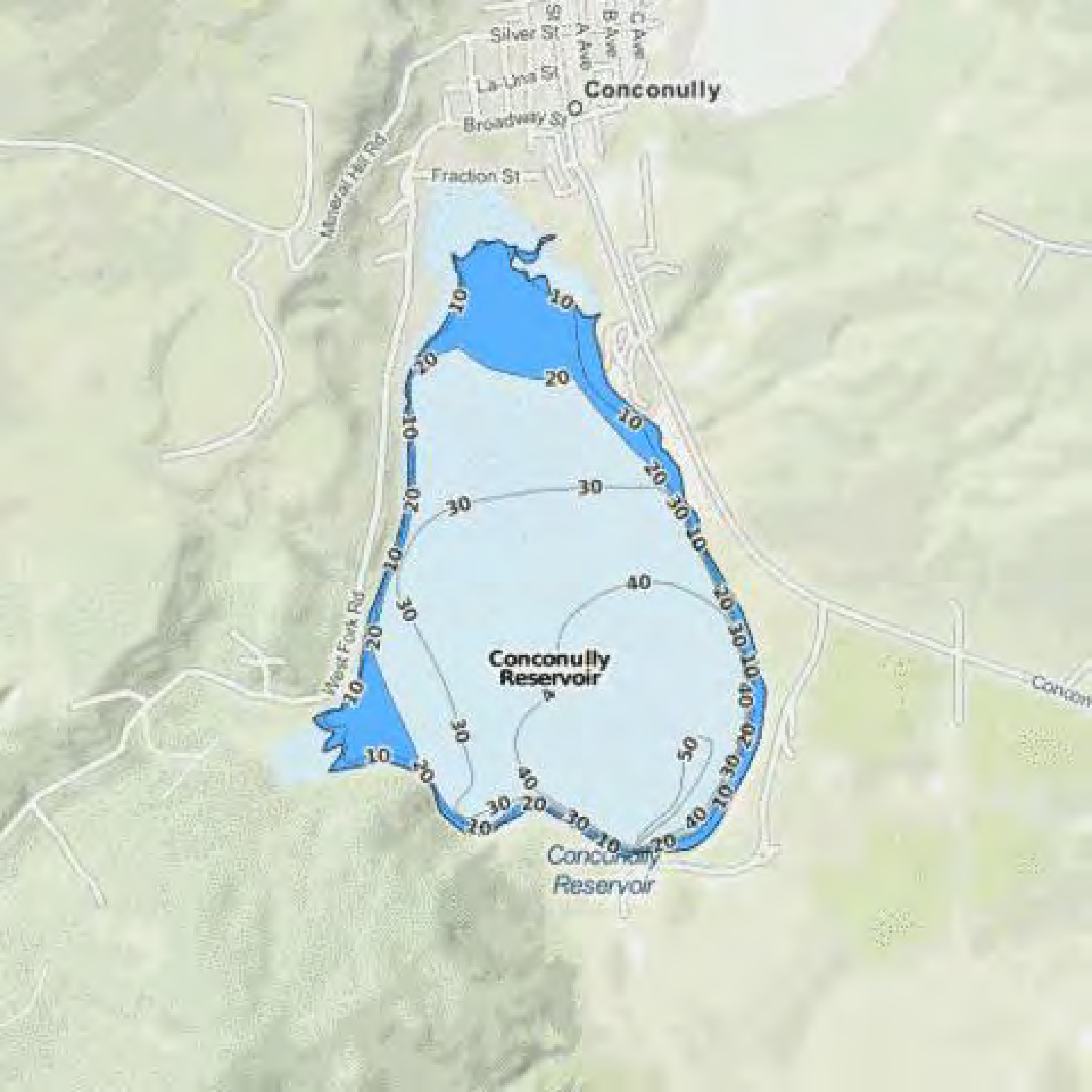
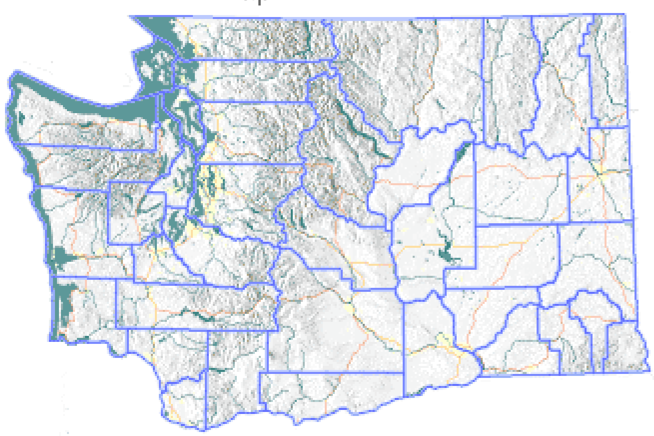


Silver St
La-Una St
Conconully
Broadway St
Fraction St
Mineral Hill Rd
West Fork Rd
Conconully Reservoir
10
20
30
40
50
Conconully
Reservoir

Department of Ecology Aquatic Plant Monitoring

Conconully (Salmon) Lake

County	Okanogan
Latitude	48.55806
Longitude	119.7444
Ecoregion	Columbia Basin
years surveyed	2003, 1997, 1994
map link	



Species

scientific name	common name
Alisma gramineum	narrowleaf water-plantain
Callitriche hermaphroditica	northern water-starwort
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Elodea canadensis	common elodea
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum sp.	water-milfoil
Myriophyllum spicatum	Eurasian water-milfoil
Nitella sp.	stonewort
Phalaris arundinacia	reed canarygrass
Potamogeton foliosus	leafy pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton sp.	pondweed
Ranunculus aquatilis	water-buttercup
Scirpus sp.	bulrush
Stuckenia pectinata	sago pondweed

Stuckenia sp.	pondweed
unknown plant	unknown

Detailed results

sort results on species · sort results on date

species	date	DV[1]	source[2]	comment
Alisma gramineum	7/26/1994	2	Ecology	
Callitriche hermaphroditica	7/26/1994	1	"	
Ceratophyllum demersum	7/26/1994	2	"	
"	9/20/2003	1	"	
Chara sp.	7/26/1994	2	"	
"	9/20/2003	2	"	
Elodea canadensis	7/26/1994	2	"	
"	9/20/2003	2	"	
Myriophyllum sibiricum	7/26/1994		"	
"	9/20/2003	1	"	
Myriophyllum sp.	7/26/1994	3	"	not sure if M. spicatum
Myriophyllum spicatum	5/31/1997		"	ID confirmed by chromatography
"	9/20/2003	4	"	some a hybrid with M. sibiricum. Saw Triaenodes larvae
Nitella sp.	7/26/1994	1	"	
Phalaris arundinacia	9/20/2003	3	"	on shore
Potamogeton foliosus	7/26/1994	1	"	
"	9/20/2003	2	"	with achenes
Potamogeton illinoensis	7/26/1994	3	"	
"	9/20/2003	2	"	
Potamogeton sp (thin leaved)	7/26/1994	2	"	
"	9/20/2003	1	"	species other than P. foliosus
Potamogeton sp.	7/26/1994	1	"	may be P. alpinus?
Ranunculus aquatilis	7/26/1994	2	"	
Scirpus sp.	7/26/1994		"	on shore
Stuckenia pectinata	7/26/1994	2	"	
Stuckenia sp.	9/20/2003	1	"	S. vaginata?
unknown plant	7/26/1994	2	"	

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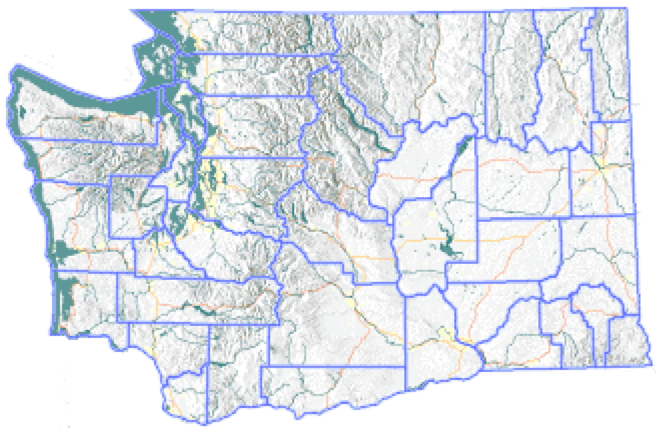
Fish Lake

County	Okanogan
Latitude	48.61
Longitude	119.6842
Ecoregion	Columbia Basin
years surveyed	2007, 1999, 1994
map link	



Species

scientific name	common name
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Fontinalis antipyretica	water moss
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum sp.	water-milfoil
Polygonum amphibium	water smartweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton natans	floating leaf pondweed
Potamogeton pusillus	slender pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Ranunculus aquatilis	water-buttercup
Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Stuckenia pectinata	sago pondweed
Typha latifolia	common cat-tail
Typha sp.	cat-tail

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Ceratophyllum demersum	7/26/1994	3	Ecology	most dense at west end
"	7/14/1999	2	"	
"	6/19/2007	3	"	large patches in shallow north end
Chara sp.	7/26/1994	4	"	most dense at west end
"	7/14/1999	4	"	dominant
"	6/19/2007	4	"	dominant
Fontinalis antipyretica	7/14/1999	1	"	
Myriophyllum sibiricum	7/26/1994	2	"	near boatlaunch
"	7/14/1999	1	"	only saw a few
Myriophyllum sp.	6/19/2007	2	"	looked like M. verticillatum, not flowering
Polygonum amphibium	7/26/1994	3	"	
"	7/14/1999	2	"	
"	6/19/2007	3	"	along most of shallow water shoreline
Potamogeton gramineus	6/19/2007		"	in sample bag
Potamogeton illinoensis	7/26/1994	3	"	most dense at west end
"	7/14/1999	2	"	
"	6/19/2007	3	"	some with sessile leaves
Potamogeton natans	6/19/2007	2	"	mostly in north end
Potamogeton pusillus	7/26/1994	2	"	
"	6/19/2007	2	"	may be another species of thin leaved pondweed too
Potamogeton sp (thin leaved)	7/14/1999	2	"	
Ranunculus aquatilis	6/19/2007	3	"	blooming
Schoenoplectus sp.	6/19/2007	2	"	bulrush
Scirpus sp.	7/26/1994	2	"	on shore
"	7/14/1999	2	"	
Stuckenia pectinata	7/26/1994	2	"	
"	7/14/1999	2	"	
"	6/19/2007	3	"	mostly in north end
Typha latifolia	7/14/1999	2	"	
"	6/19/2007	3	"	
Typha sp.	7/26/1994	2	"	on shore

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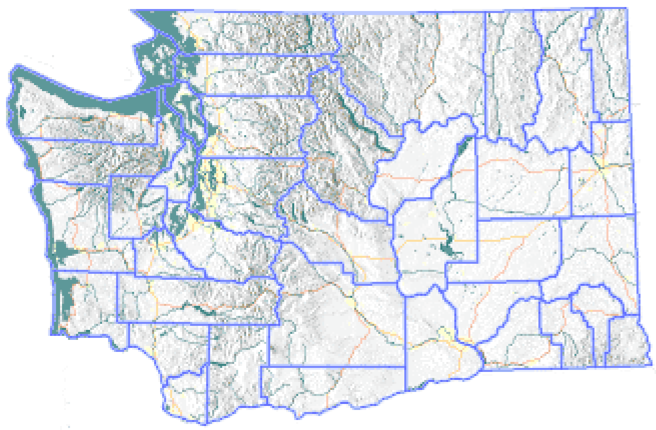
Forde Lake

County	Okanogan
Latitude	48.73667
Longitude	119.6683
Ecoregion	Columbia Basin
years surveyed	2007
map link	



Species

scientific name	common name
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Elodea sp.	waterweed
Lemna sp.	duckweed
Lemna trisulca	star duckweed
Myriophyllum sibiricum	northern watermilfoil
Potamogeton gramineus	grass-leaved pondweed
Potamogeton natans	floating leaf pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Ranunculus aquatilis	water-buttercup
Sparganium sp.	bur-reed
Spirodela polyrrhiza	great duckweed
Stuckenia filiformis	slender leaved pondweed
Typha latifolia	common cat-tail
unknown plant	unknown
Utricularia vulgaris	common bladderwort

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Carex sp.	6/20/2007	1	Ecology, Okanogan Co NWCB	
Ceratophyllum demersum	6/20/2007	4	"	large mats
Chara sp.	6/20/2007	4	"	covered bottom with other species growing through the mat
Elodea sp.	6/20/2007	3	"	
Lemna sp.	6/20/2007	3	"	
Lemna trisulca	6/20/2007		"	in sample bag
Myriophyllum sibiricum	6/20/2007		"	in sample bag
Potamogeton gramineus	6/20/2007	2	"	
Potamogeton natans	6/20/2007	3	"	large patches
Potamogeton sp (thin leaved)	6/20/2007	2	"	
Ranunculus aquatilis	6/20/2007	3	"	with white flowers
Sparganium sp.	6/20/2007		"	seedlings with seeds
Spirodela polyrrhiza	6/20/2007		"	in sample bag
Stuckenia filiformis	6/20/2007	2	"	
Typha latifolia	6/20/2007	3	"	
unknown plant	6/20/2007		"	small delicate moss, may be Fontinalis
Utricularia vulgaris	6/20/2007	2	"	

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Department of Ecology Aquatic Plant Monitoring

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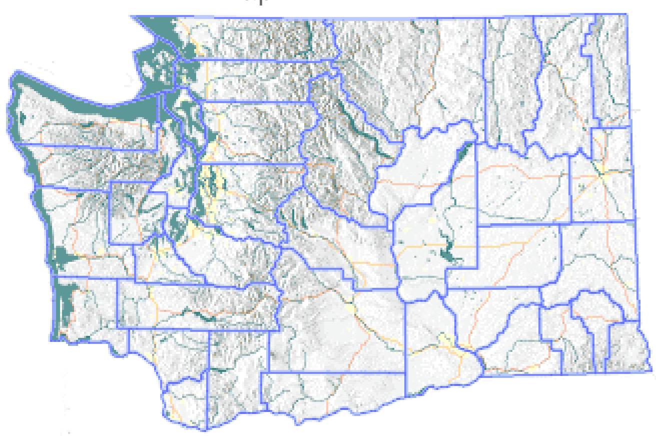
Leader Lake

County	Okanogan
Latitude	48.36139
Longitude	119.6958
Ecoregion	Columbia Basin
years surveyed	2003, 1996
map link	



Species

scientific name	common name
Callitriche hermaphroditica	northern water-starwort
Chara sp.	muskwort
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Myriophyllum sibiricum	northern watermilfoil
Polygonum amphibium	water smartweed
Potamogeton foliosus	leafy pondweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton nodosus	longleaf pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton sp.	pondweed
Ranunculus aquatilis	water-buttercup
Salix sp.	willow
Stuckenia pectinata	sago pondweed

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Callitriche hermaphroditica	8/29/1996	2	Ecology	in shallows
"	9/20/2003		"	with fruit. Only inventoried part of the lake from shore
Chara sp.	8/29/1996	4	"	carpets the bottom on North side
"	9/20/2003		"	
Eleocharis sp.	8/29/1996	3	"	dense on ungrazed shore
"	9/20/2003		"	small one in shallows and muddy shore
Elodea canadensis	8/29/1996	4	"	dense on south shore
"	9/20/2003		"	
Myriophyllum sibiricum	8/29/1996	2	"	
"	9/20/2003		"	
Polygonum amphibium	8/29/1996	2	"	
Potamogeton foliosus	8/29/1996	2	"	
Potamogeton gramineus	8/29/1996	3	"	surfacing
"	9/20/2003		"	
Potamogeton nodosus	9/20/2003		"	
Potamogeton sp (thin leaved)	9/20/2003		"	
Potamogeton sp.	8/29/1996	1	"	cross, gramineus x illinoensis?
Ranunculus aquatilis	8/29/1996	1	"	couple of plants, south shore
Salix sp.	8/29/1996	2	"	looks dead in many areas
Stuckenia pectinata	8/29/1996	2	"	
"	9/20/2003		"	

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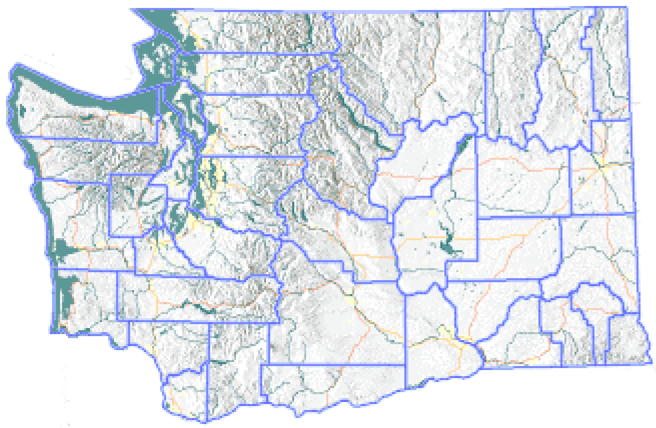
Palmer Lake

County	Okanogan
Latitude	48.91083
Longitude	119.6453
Ecoregion	Cascades
years surveyed	2010, 2007, 2005, 1999, 1995, 1994
map link	



Species

scientific name	common name
Bolboschoenus fluviatilis	river bulrush
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Elodea sp.	waterweed
Equisetum sp.	horse tail
Heteranthera dubia	water star-grass
Juncus sp.	rush
Juncus sp. or Eleocharis sp.	small grass-like plants
Mentha sp.	mint
Myriophyllum hippuroides	western watermilfoil
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum spicatum	Eurasian water-milfoil

Najas flexilis	common naiad
Nuphar polysepala	yellow water-lily
Polygonum amphibium	water smartweed
Potamogeton alpinus	red pondweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton natans	floating leaf pondweed
Potamogeton nodosus	longleaf pondweed
Potamogeton praelongus	whitestem pondweed
Potamogeton richardsonii	Richardson's pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton zosteriformis	eel-grass pondweed
Ranunculus aquatilis	water-buttercup
Sagittaria sp.	arrowhead
Salix sp.	willow
Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Sparganium sp.	bur-reed
Stuckenia filiformis	slender leaved pondweed
Stuckenia pectinata	sago pondweed
Stuckenia sp.	pondweed
unknown plant	unknown
Zannichellia palustris	horned pondweed

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Bolboschoenus fluviatilis	6/28/1995	3	Ecology	thick patch at north end
"	7/13/1999	2	"	at north end
"	8/18/2005		"	along north shore
"	7/4/2010	3	"	north end, starting to flower
Carex sp.	8/18/2005	2	"	
"	6/19/2007	2	"	more than one species
"	7/4/2010	2	"	
Ceratophyllum demersum	7/27/1994		"	only observed from shore
"	6/28/1995	2	"	
"	7/13/1999	1	"	
"	8/18/2005	2	"	mostly at north end
"	6/19/2007	2	"	
"	7/4/2010	2	"	
Chara sp.	7/13/1999	1	"	
"	8/18/2005	2	"	

Eleocharis sp.	6/19/2007	1	"	
Elodea canadensis	6/28/1995	2	"	
"	8/18/2005	2	"	
Elodea sp.	7/27/1994		"	
"	7/13/1999	2	"	may be E. nuttallii--long, narrow leaves
"	6/19/2007	2	"	looked like E. nuttallii
"	7/4/2010	2	"	
Equisetum sp.	7/13/1999	2	"	
"	8/18/2005	1	"	north end
"	7/4/2010	2	"	
Heteranthera dubia	7/13/1999	1	"	
"	8/18/2005	2	"	often growing in shallow water
"	7/4/2010	1	"	
Juncus sp.	6/19/2007	1	"	
"	7/4/2010	2	"	
Juncus sp. or Eleocharis sp.	6/19/2007		"	
"	7/4/2010	2	"	
Mentha sp.	7/13/1999	2	"	
"	8/18/2005	2	"	
Myriophyllum hippuroides	7/13/1999	1	"	not flowering
Myriophyllum sibiricum	7/27/1994		"	
"	6/28/1995	1	"	
"	7/13/1999	1	"	
Myriophyllum spicatum	7/13/1999	2	"	most at north end by wetland
"	8/18/2005	5	"	dominant where there is habitat, especially between 1-4 m deep
"	6/19/2007	2	"	mostly fragments in south end, rooted plants in north (see map)
"	7/4/2010	2	"	rooted plants in deeper water, none approaching surface, but water level was high, many fragments floating in north half of lake
Najas flexilis	7/27/1994		"	
Nuphar polysepala	6/28/1995	2	"	at north end
"	7/13/1999	2	"	at north end
"	8/18/2005	1	"	north end
"	6/19/2007	1	"	wetland shallows west of launch
"	7/4/2010	2	"	north end
Polygonum amphibium	6/28/1995	2	"	
"	7/13/1999	3	"	
"	8/18/2005	2	"	mostly at north end in shallow muddy areas
"	6/19/2007	3	"	not blooming yet

"	7/4/2010	2	"	
Potamogeton alpinus	8/18/2005	2	"	dense patch at north end
Potamogeton gramineus	7/13/1999	2	"	
"	8/18/2005	2	"	often low growing
"	6/19/2007		"	
"	7/4/2010	2	"	
Potamogeton illinoensis	7/27/1994		"	
"	6/28/1995	2	"	
"	7/13/1999	1	"	
"	8/18/2005	1	"	a couple of small patches on west side
"	6/19/2007	3	"	
Potamogeton natans	6/28/1995	2	"	mostly at north end
"	7/13/1999	2	"	
"	8/18/2005	2	"	
"	6/19/2007	3	"	
"	7/4/2010	2	"	
Potamogeton nodosus	6/28/1995	2	"	at north end
"	7/13/1999	3	"	
"	8/18/2005	2	"	
"	6/19/2007	3	"	large patches in north end
"	7/4/2010	3	"	dense at north end
Potamogeton praelongus	7/27/1994		"	
"	8/18/2005	1	"	north end only
"	6/19/2007		"	
"	7/4/2010	2	"	
Potamogeton richardsonii	7/13/1999	2	"	
"	8/18/2005	1	"	north end
"	6/19/2007	2	"	
"	7/4/2010	2	"	
Potamogeton sp (thin leaved)	7/27/1994		"	
"	7/13/1999	1	"	
"	8/18/2005	2	"	no achenes for ID to species
"	6/19/2007	1	"	very small plants
"	7/4/2010	1	"	
Potamogeton zosteriformis	8/18/2005	3	"	
"	6/19/2007	1	"	
"	7/4/2010	2	"	

Ranunculus aquatilis	6/28/1995	1	"	
"	7/13/1999	1	"	
"	8/18/2005	2	"	flowering
"	6/19/2007	1	"	around boat launch
"	7/4/2010	1	"	
Sagittaria sp.	8/18/2005	1	"	north end, shallow water. Looked like S. latifolia
Salix sp.	7/4/2010	2	"	along shore, in water today
Schoenoplectus sp.	8/18/2005	2	"	mostly at north end
"	6/19/2007	2	"	large expanse in north end
"	7/4/2010	2	"	
Scirpus sp.	7/13/1999	2	"	bulrush
Sparganium sp.	7/13/1999	1	"	at north end
"	7/4/2010	1	"	north end wetland
Stuckenia filiformis	6/19/2007		"	
Stuckenia pectinata	7/27/1994		"	
"	6/28/1995	2	"	
"	7/13/1999	2	"	
"	8/18/2005	3	"	
"	6/19/2007	3	"	large patches
"	7/4/2010	2	"	
Stuckenia sp.	7/4/2010	2	"	
unknown plant	7/13/1999	1	"	same unknown plant as that in Munn Lake
"	6/19/2007		"	possibly a Polygonum species
"	7/4/2010	2	"	grass species, growing in water
Zannichellia palustris	7/13/1999	1	"	

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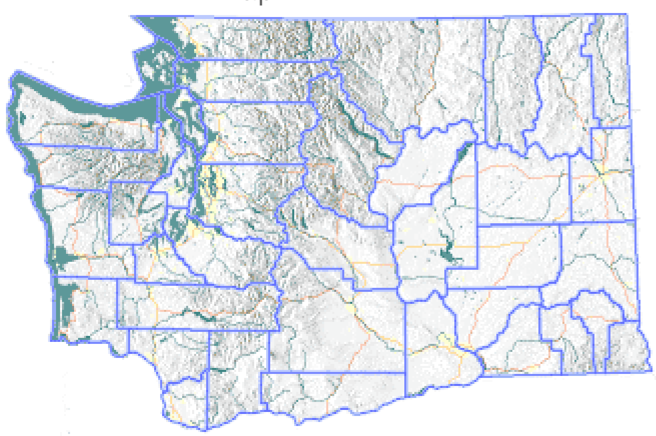
Patterson Lake

County	Okanogan
Latitude	48.46639
Longitude	120.2497
Ecoregion	Columbia Basin
years surveyed	1999, 1995
map link	



Species

scientific name	**common name**
Alisma triviale	American water-plantain
Chara sp.	muskwort
Eleocharis sp.	spike-rush
Elodea canadensis	common elodea
Fontinalis antipyretica	water moss
Juncus sp. or Eleocharis sp.	small grass-like plants
Myriophyllum sibiricum	northern watermilfoil
Nitella sp.	stonewort
Potamogeton crispus	curly leaf pondweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Ranunculus sp.	buttercup
Sagittaria cuneata	Arumleaf arrowhead, wapato
Scirpus sp.	bulrush
Stuckenia pectinata	sago pondweed

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Alisma triviale	8/10/1995	2	Ecology	along margins
Chara sp.	8/10/1995	2	"	
"	8/10/1999	4	"	dominant submrsed plant
Eleocharis sp.	8/10/1999	2	"	tiny shoreline one, flowering
Elodea canadensis	8/10/1995	3	"	some large patches
"	8/10/1999	2	"	mostly in deep water--much with no leaves
Fontinalis antipyretica	8/10/1999	1	"	
Juncus sp. or Eleocharis sp.	8/10/1995	2	"	shallows
Myriophyllum sibiricum	8/10/1999	2	"	
Nitella sp.	8/10/1995	2	"	deep water
"	8/10/1999	2	"	in deep water
Potamogeton crispus	8/10/1995	3	"	
"	8/10/1999	2	"	
Potamogeton gramineus	8/10/1995	3	"	variable morphology depending on depth
"	8/10/1999	3	"	Some strange forms
Potamogeton sp (thin leaved)	8/10/1995	1	"	
Ranunculus sp.	8/10/1995	2	"	in deeper water
Sagittaria cuneata	8/10/1999	2	"	
Scirpus sp.	8/10/1995	1	"	
Stuckenia pectinata	8/10/1995	3	"	
"	8/10/1999	3	"	

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
2. "Source" is the organization that provided the data. "Ecology" refers to the Washington State Department of Ecology.

Washington State Department of Ecology

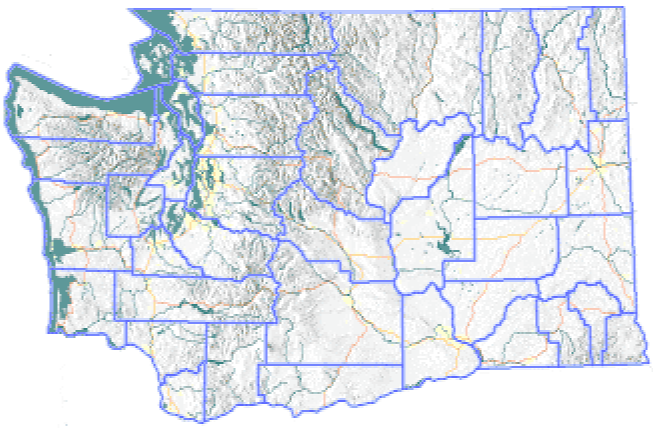
Questions or comments may be sent to Jenifer Parsons, Environmental Assessment Program, Central Regional Office.

Department of Ecology Aquatic Plant Monitoring

Ecology home > environmental information > aquatic plant monitoring

Sidley Lake

County	Okanogan
Latitude	48.98833
Longitude	119.2156
Ecoregion	Columbia Basin
years surveyed	2009, 1996
map link	



Species

scientific name	common name
Phalaris arundinacia	reed canarygrass
Schoenoplectus tabernaemontani	softstem bulrush
Scirpus sp.	bulrush
Stuckenia pectinata	sago pondweed
Typha sp.	cat-tail

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Phalaris arundinacia	10/10/2009		Ecology	
Schoenoplectus tabernaemontani	10/10/2009		"	growing along shore
Scirpus sp.	8/27/1996		"	

Stuckenia pectinata	8/27/1996		"	only observed from shore
"	10/10/2009		"	
Typha sp.	8/27/1996		"	

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
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Washington State Department of Ecology

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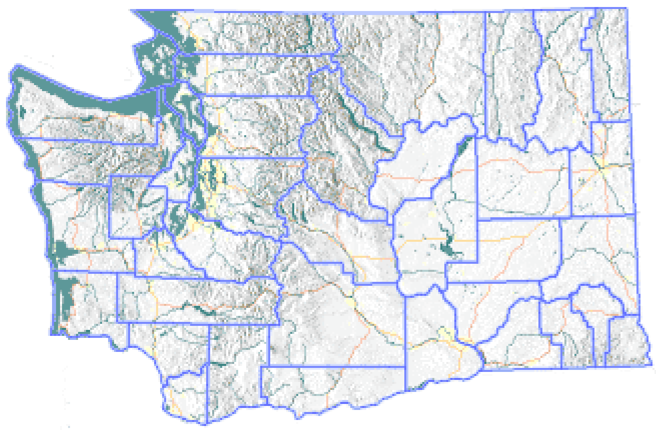
Spectacle Lake

County	Okanogan
Latitude	48.81528
Longitude	119.5222
Ecoregion	Columbia Basin
years surveyed	2012, 2009, 2005, 1999, 1997, 1996, 1994
map link	



Species

scientific name	common name
Alisma gramineum	narrowleaf water-plantain
Callitriche hermaphroditica	northern water-starwort
Callitriche sp.	water-starwort
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Elodea canadensis	common elodea
Elodea nuttallii	Nuttall's waterweed
Juncus sp.	rush
Juncus sp. or Eleocharis sp.	small grass-like plants
Lythrum salicaria	purple loosestrife
Myriophyllum hybrid	hybrid of Eurasian and northern milfoils
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum spicatum	Eurasian water-milfoil
Najas flexilis	common naiad
Nitella sp.	stonewort
Phalaris arundinacia	reed canarygrass
Polygonum amphibium	water smartweed

Potamogeton crispus	curly leaf pondweed
Potamogeton foliosus	leafy pondweed
Potamogeton gramineus	grass-leaved pondweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton pusillus	slender pondweed
Potamogeton richardsonii	Richardson's pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Potamogeton sp.	pondweed
Ranunculus aquatilis	water-buttercup
Schoenoplectus acutus	hardstem bulrush
Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Sparganium sp.	bur-reed
Stuckenia pectinata	sago pondweed
Typha latifolia	common cat-tail
Typha sp.	cat-tail
unknown plant	unknown

Detailed results

sort results on species   sort results on date

species	date	DV[1]	source[2]	comment
Alisma gramineum	7/27/1994	1	Ecology	
Callitriche hermaphroditica	7/27/1994	2	"	
"	8/27/1996	1	"	in shallows
"	9/17/1997	2	"	
Callitriche sp.	10/9/2009		"	growing around launch area, only looked from shore
Ceratophyllum demersum	7/27/1994	2	"	
"	8/27/1996	3	"	
"	9/17/1997	2	"	
"	7/14/1999	2	"	
"	8/18/2005	4	"	dominant in deep water
"	7/3/2012	2	"	
Chara sp.	7/27/1994	2	"	
"	8/27/1996	1	"	
"	9/17/1997	2	"	
"	7/14/1999	2	"	
"	8/18/2005	2	"	
"	7/3/2012	2	"	
Elodea canadensis	7/27/1994	4	"	thick in many areas
"	8/27/1996	2	"	

"	9/17/1997	3	"	dense patches
"	7/14/1999	3	"	
"	8/18/2005	4	"	dense, especially in northwest end
"	10/9/2009		"	dense at east end
"	7/3/2012	2	"	
Elodea nuttallii	7/3/2012	1	"	narrow leaves
Juncus sp.	7/3/2012	2	"	
Juncus sp. or Eleocharis sp.	7/27/1994	1	"	
"	9/17/1997	2	"	
Lythrum salicaria	8/18/2005	1	"	two small patches, northeast side
Myriophyllum hybrid	7/3/2012	3	"	dense in places, near shore. Confirmed with genetic analysis (Thum)
Myriophyllum sibiricum	7/27/1994	2	"	
"	8/27/1996	2	"	mostly at east end
"	9/17/1997	2	"	
"	7/14/1999	2	"	most at west end
"	8/18/2005	4	"	dominant, often topped out about 30 ft from shore
"	7/3/2012	2	"	some looked non-hybrid, but difficult to tell
Myriophyllum spicatum	7/3/2012	2	"	some looked 'classic', presence confirmed with genetic analysis
Najas flexilis	8/18/2005	2	"	in shallows
Nitella sp.	7/14/1999	1	"	deep water
Phalaris arundinacia	8/27/1996	3	"	thick in spots along shore
"	9/17/1997	3	"	
"	7/14/1999	3	"	
"	8/18/2005	3	"	
"	7/3/2012	2	"	
Polygonum amphibium	8/27/1996	2	"	
"	7/14/1999	2	"	
"	7/3/2012	1	"	
Potamogeton crispus	7/3/2012	2	"	
Potamogeton foliosus	8/18/2005	2	"	mostly in shallow water
Potamogeton gramineus	7/14/1999	1	"	
"	8/18/2005	1	"	northwest end
Potamogeton illinoensis	7/27/1994	4	"	thick in many areas
"	8/27/1996	3	"	surfacing in some areas
"	9/17/1997	3	"	some thick surfacing patches
"	7/14/1999	4	"	
"	8/18/2005	3	"	widespread, dominant in patches
"	7/3/2012	1	"	
Potamogeton pusillus	7/27/1994	2	"	
"	7/14/1999	3	"	
"	7/3/2012	3	"	

Potamogeton richardsonii	8/27/1996	1	"	at east end, may be a cross
Potamogeton sp (thin leaved)	7/27/1994		"	
"	8/27/1996	2	"	
"	9/17/1997	1	"	
Potamogeton sp.	7/27/1994	2	"	looks like a cross P. alpinus x illinoensis
Ranunculus aquatilis	7/27/1994	2	"	
"	7/14/1999	3	"	
"	8/18/2005	2	"	flowering
"	7/3/2012	2	"	blooming
Schoenoplectus acutus	8/18/2005	2	"	
Schoenoplectus sp.	7/3/2012	2	"	
Scirpus sp.	7/27/1994	2	"	
"	9/17/1997	2	"	
"	7/14/1999	2	"	
Sparganium sp.	8/18/2005	1	"	all submersed, bright green leaves, in shallows at boat launch
"	10/9/2009		"	some at east end in dense elodea
Stuckenia pectinata	7/27/1994	2	"	
"	8/27/1996	2	"	
"	9/17/1997	2	"	
"	7/14/1999	4	"	
"	8/18/2005	3	"	
Typha latifolia	7/14/1999	2	"	
"	8/18/2005	2	"	
"	7/3/2012	2	"	
Typha sp.	7/27/1994	2	"	
"	8/27/1996	2	"	
"	9/17/1997	2	"	
unknown plant	8/27/1996	1	"	Rorippa sp?

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
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Washington State Department of Ecology

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Lakeland Restoration Services, LLC
78 E River Spur Rd, Priest River, ID 83856
Phone/Fax: (208) 448-2222
www.lakelandrs.com

2014 Spectacle Lake Aquatic Plant Management Project

Introduction:

Lakeland Restoration Services LLC performed a survey on September 24 2013. Spectacle Lake is a summer drawdown reservoir. The Littoral zone at full pool is 21 ft. The Lake was surveyed at 1364, which is below full pool. The littoral zone was infested with 95% Eurasian Water Milfoil.

The average depth of the infestation was at 10 ft. at full pool.

At that time there was approximately 79 acres of infested Reservoir, at an average of 10 ft. which translates to 790 acre ft. of necessary treatment.

For the 2014 season the newly formed Spectacle Lake Association contracted Lakeland Restoration Services (LRS) for Eurasian Water Milfoil treatment. LRS treated only treated 33 acres on June 12th, 2014 (Included Appendix A: Treatment Maps)

Public & Agency Notifications/Shoreline Posting

The following is a list of notifications that were delivered as required by the Washington State Department of Ecology Aquatic Plant and Algae Management General Permit # WAG994205:

- Business and Residential Notices were distributed on June 2, 2014 by LRS, to residents within ¼ mile of proposed treatment areas. Letters provided LRS website and phone line information for further information and questions. *(Letter included: Appendix B)*

- Shoreline Notices were printed on white paper and posted (Appendix C). Signs were posted facing the water and the shore and were placed on each private or public property within 10 feet of shoreline, within 400 feet of the treatment area, and within every 100 feet along the shoreline and docks with in treatment areas and potentially affected areas.

- Public Access signs, 2 feet by 3 feet in size were posted at each public access area along with a 8 ½ x 11 map showing the reader's location and the treatment areas. (Notice attached – see Appendix C).

- Pre and Post Treatment Notification were submitted to WA Dept. of Ecology June 11th and June 12th, 2014 *(Included Appendix D)*

Public Outreach

- Lakeland Restoration Services LLC attended a public meeting with the Spectacle Lake Association on May 22, 2014.

- Internet: A LRS website project page was posted at www.lakelandrs.com, dedicated specifically to the Diamond Lake. The page includes information about how the project would proceed, what the public could expect in the way of restrictions, the kind of herbicide being used and maps of the lake showing where herbicide treatment would occur.

- Email: An email contact address, info@lakelandrs.com was available, giving the public a means to ask questions directly of the contractor and irrigation district. These emails were routed to a LRS representative that returned the answer via email or phone call if requested by the customer.

- Phone: A toll-free, dedicated phone number (877-273-6674) was available which gave the public pre-recorded information about the project. Information became available for the Diamond Lake project on June 1, 2014. The number allowed customers to leave a message, and a return call was made by a LRS representative to answer any questions or concerns.

Personnel

The following personnel were present for this project:

- David Kluttz – License # 66448 – Applicator/Airboat Pilot
- Jake Nesbitt – License #88023 – Applicator/Airboat Pilot
- Cathy Allen – Mixer/Loader Cert. – Mixer/Loader/ Shoreline Posting
- Jessie Griffin – Mixer/Loader Cert. – Mixer/Loader/ Shoreline Posting
- Jalen Griffin – Mixer/Loader Cert. – Mixer/Loader/ Shoreline Posting

Product Information

The following table outlines the average depth, total surface acres, and amount of herbicides applied by treatment area for the aquatic portion of the project. (Treatment maps attached – see Appendix A):

The liquid aquatic herbicides Reward® (Diquat) and DMA 4 IVM® (2, 4-D) were used for the aquatic treatment to control EWM

2014 Spectacle Lake Inventory Sheet
TREATMENT AREAS

Area	Avg Depth	Surface Acres	2,4-D (gallons)	#of containers	Load 1	Diquat (gallons)	#of containers	Load 1	Clipper (pounds)	# of bags	Load 1
1	10	3.2	67.0	26.0		5.0	2.0				
2	10	3.1	66.0	26.0		5.0	2.0				
3	10	3	65.5	26.0		4.5	1.5				
4	10	3	65.5	26.0		5.0	2.0				
5	10	1.2	25.0	10.0		1.0	0.5				
6	10	3	65.5	26.0		5.0	2.0				
7	10	3.4	68.0	27.0		5.0	2.0				
8	10	3.5	69.0	27.0		5.0	2.0				
9	10	3.4	68.0	27.0		5.0	2.0				
10	10	3	65.5	26.0		4.5	1.5				
11	10	2.9				5.0	2.0		15.0	15.0	
Totals:		32.7	625.0	247.0		50.0	19.5		15.0	15.0	

Area 1-10: 2,4-D 2.25 gal/acre foot

Area 1-11: Diquat 1.5 gal/acre foot

Area 11: Clipper

In the areas within 1400 ft. of irrigation outlets, a product called Clipper, a Valent product was used. There are few irrigation restrictions with this product. Clipper can be used with Diquat, and that increased the irrigation restrictions to 3 days.

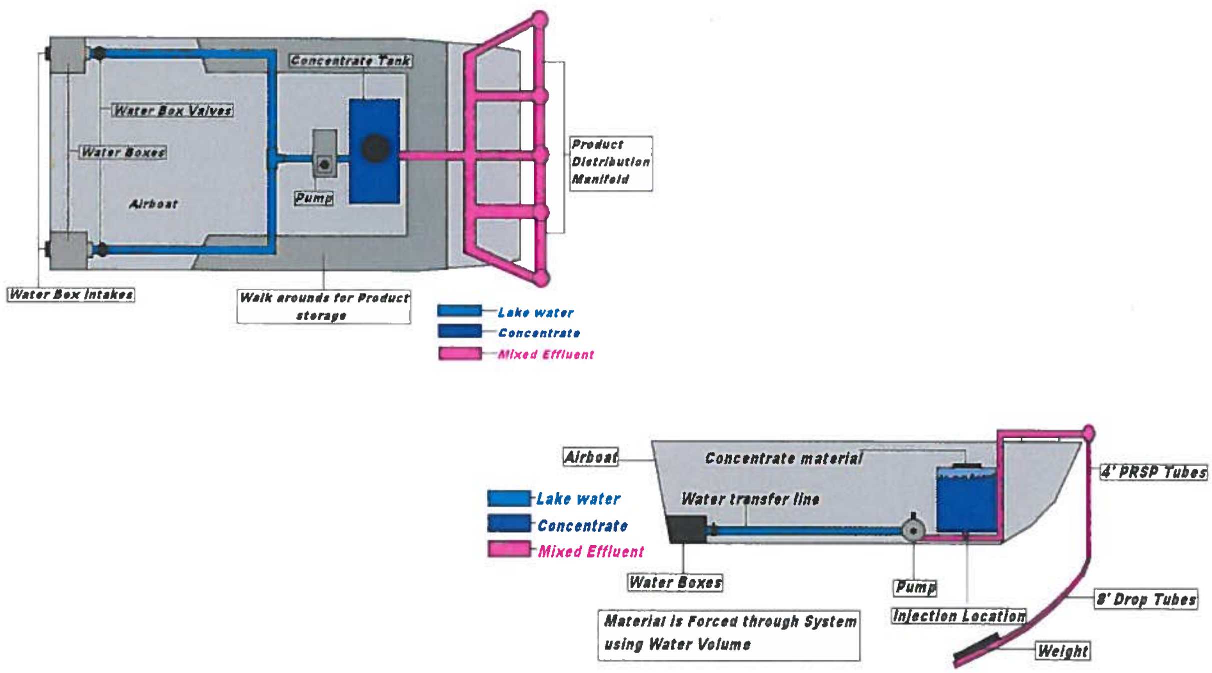
WSDA Pesticide Application Records (PARS) were completed for each day of application. PARS will be retained with this file for seven years as required by the WSDA. (Included: Appendix E)

Treatment Methodology

The application of DMA 4 IVM® accomplished using 1 airboat using the following methodology:

DMA 4 IVM® was applied at an average speed of 5 mph using a manifold boom style sub-surface injection system that is attached to the airboat (pictures at right/diagram below). The collection side of the system gathers lake water from built in water boxes at the rear of the boat using a high volume, close tolerance pump powered by a 5hp Honda motor. The pump generates pressure through a manifold system causing a venturi effect, which pulls the concentrate from the tank, thereby mixing it with the lake water to be injected directly into the water column through the manifold boom. The boom is 8' wide and has 5 drop tubes, each 4' long.

Diagram A-1: Liquid Injection System – top view/side view



Herbicide was continually poured from each 2.5 gallon container into a 25 gallon tank insuring a consistent application. Each container was triple-rinsed in the treatment area during the treatment, rendered incapable of reuse, and taken to a local landfill.

Chemical and DO Monitoring

After completion of the treatment, a 40 MPH wind began blowing from the west. As the lake is in a draw with the longest length east and west, herbicides were moved along the shoreline. This undoubtedly diluted the treatment to some degree.

Logs, Maps, and Tracking

The entire treatment was monitored with the use of Global Positioning System (GPS) technology. Treatment routes were pre-planned using Arcview, and pre-loaded into 2 GPS devices.

Following the treatment, tracks were downloaded into Arcview, and analyzed for thoroughness of the treatment.

Environmental Protection Measures/Safety Equipment

In order to minimize spills, herbicide was manually loaded directly into a nurse boat from its on-shore storage location. The nurse boat delivered the product directly to the application boat, which remained in the treatment areas throughout the day. Herbicide was inventoried each time it was loaded onto the application boat to insure the correct amount of herbicide was applied to each area. Empty containers were retrieved and taken to a local landfill.

Personal Protection Equipment was provided to workers, as per the herbicide label information, and a spill kit and absorption materials were available near the loading site and with the boat to be used in the unlikely event of a spill. (Appendix F: Safety Plan)

Application Summary and Recommendations:

35 acres were slated for treatment. Surveys conducted after the treatment by Bob Rothrock and Mike Lesky confirm that as much as 50 acres may have been controlled on the initial application.

Much more Curly Leaf pondweed was noticed during treatment than was observed last fall. To better control that plant, I recommend using Aquathol @ 2ppm along with 2, 4-D or Tryclopyr to control EWM in subsequent applications.

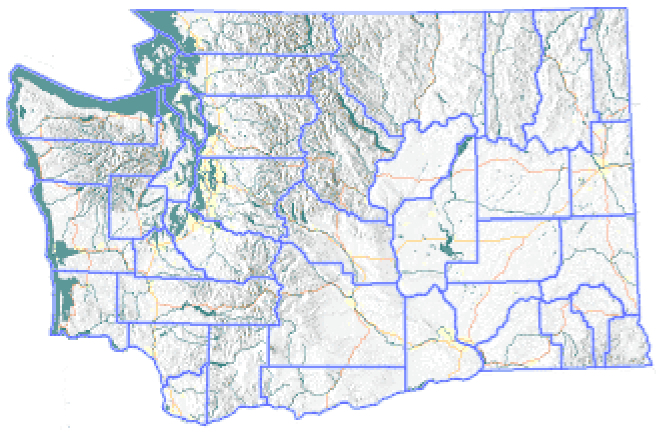
Mike Lesky had suggested two more years of applications. In 2015, complete the treatment of the remaining untreated areas during full pool in May. In 2016, treat the areas in the deep parts of the littoral zone after drawdown. Some regrowth was observed in areas deeper than 17 ft. at full pool. After drawdown, those areas would be less than 7 ft., herbicide performance will be increased at shallower depths.

Department of Ecology Aquatic Plant Monitoring

Ecology home > environmental information > aquatic plant monitoring

Whitestone Lake

County	Okanogan
Latitude	48.7875
Longitude	119.4636
Ecoregion	Columbia Basin
years surveyed	2010, 2009, 2005, 1999, 1997, 1996, 1995, 1994
map link	



Species

scientific name	common name
Alisma sp.	waterplantain
Bolboschoenus maritimus	seacoast bulrush
Carex sp.	sedge
Ceratophyllum demersum	Coontail; hornwort
Chara sp.	muskwort
Eleocharis sp.	spike-rush
Juncus sp.	rush
Juncus sp. or Eleocharis sp.	small grass-like plants
Lythrum salicaria	purple loosestrife
Myriophyllum sibiricum	northern watermilfoil
Myriophyllum spicatum	Eurasian water-milfoil
Phalaris arundinacia	reed canarygrass
Polygonum amphibium	water smartweed
Potamogeton illinoensis	Illinois pondweed
Potamogeton sp (thin leaved)	thin leaved pondweed
Ranunculus aquatilis	water-buttercup
Rumex sp.	dock

Salix sp.	willow
[*Schoenoplectus acutus*]	[hardstem bulrush]
Schoenoplectus pungens	three-square bulrush
Schoenoplectus sp.	naked-stemmed bulrush
Scirpus sp.	bulrush
Solanum sp.	nightshade
[*Stuckenia pectinata*]	[sago pondweed]
[*Typha latifolia*]	[common cat-tail]
[*Typha sp.*]	[cat-tail]
unknown plant	unknown
Veronica anagallis-aquatica	water speedwell

Detailed results

sort results on species sort results on date

species	date	DV[1]	source[2]	comment
Alisma sp.	7/27/1994	1	Ecology	
Bolboschoenus maritimus	7/27/1994	2	"	
Carex sp.	9/17/1997	2	"	
"	8/19/2005	2	"	
Ceratophyllum demersum	7/27/1994	2	"	
"	6/28/1995	2	"	
"	8/26/1996	2	"	few thicker patches
"	9/17/1997	2	"	
"	8/19/2005	2	"	most around the launch
"	10/9/2009		"	only looked at launch area
Chara sp.	7/27/1994	5	"	very dense throughout lake
"	6/28/1995	4	"	thick, north end
"	8/26/1996	5	"	thick throughout
"	9/17/1997	5	"	dense
"	8/19/2005	5	"	thick growth with a few patchy clearings
"	10/9/2009		"	only looked at launch area
"	7/4/2010	5	"	meadow over most of substrate
Eleocharis sp.	7/4/2010	2	"	
Juncus sp.	7/27/1994	2	"	
"	7/4/2010	2	"	
Juncus sp. or Eleocharis sp.	8/19/2005	2	"	
Lythrum salicaria	7/27/1994	1	"	one patch, east end
"	8/26/1996	1	"	pulled, SE end of lake
Myriophyllum sibiricum	7/27/1994	2	"	
"	6/28/1995	1	"	near launch

"	8/26/1996	2	"	
"	9/17/1997	1	"	
"	8/19/2005	1	"	mostly at boat launch and just north
"	10/9/2009		"	only looked at launch area
"	7/4/2010	1	"	a little seen
Myriophyllum spicatum	7/27/1994	2	"	observed in 3 locations
"	6/28/1995	3	"	patches along > half of shoreline
"	8/26/1996	3	"	thick growth along 50% of shore
"	9/17/1997	3	"	mostly in very shallow water, some patches in deeper areas
"	7/13/1999		"	prevalent at lauch, surface mat by pullout to West of launch
"	8/19/2005	3	"	dense band around much of lake in shallow water
"	7/4/2010	3	"	some may be hybrid, most looked Eurasian. Dense in disturbed areas.
Phalaris arundinacia	8/19/2005	2	"	mostly in south end
"	7/4/2010	2	"	
Polygonum amphibium	7/27/1994	1	"	near launch
"	6/28/1995	1	"	near launch
"	8/26/1996	2	"	patches, few plants
"	9/17/1997	1	"	
"	7/4/2010	1	"	
Potamogeton illinoensis	7/27/1994	2	"	
"	6/28/1995	2	"	
"	8/19/2005	1	"	around launch area
"	7/4/2010	1	"	
Potamogeton sp (thin leaved)	6/28/1995	2	"	
"	8/26/1996	2	"	
Ranunculus aquatilis	6/28/1995	2	"	some with floating leaves
"	7/4/2010	1	"	southwest end of lake
Rumex sp.	6/28/1995	2	"	emergent
Salix sp.	7/4/2010	2	"	shore
Schoenoplectus acutus	8/19/2005	2	"	often in a band just deeper than Typha.
Schoenoplectus pungens	8/19/2005		"	
Schoenoplectus sp.	7/4/2010	2	"	
Scirpus sp.	7/27/1994	3	"	S. tabernaemontanii?
"	6/28/1995	2	"	
"	8/26/1996	2	"	
"	9/17/1997	3	"	
Solanum sp.	6/28/1995	2	"	
"	9/17/1997	2	"	
"	8/19/2005	3	"	

Stuckenia pectinata	7/27/1994	2	"	
"	6/28/1995	3	"	
"	8/26/1996	2	"	with seeds
"	9/17/1997	2	"	
"	8/19/2005	2	"	
"	7/4/2010	2	"	
Typha latifolia	8/19/2005	3	"	forming a band around much of shore
"	7/4/2010	2	"	
Typha sp.	6/28/1995	2	"	
"	8/26/1996	3	"	
"	9/17/1997	3	"	
unknown plant	6/28/1995	2	"	opposite leaves
Veronica anagallis-aquatica	6/28/1995	2	"	on shore

1. "DV" (distribution value) is an estimate of density: 1 - few plants in only 1 or a few locations; 2 - few plants, but with a wide patchy distribution; 3 - plants growing in large patches, codominant with other plants; 4 - plants in nearly monospecific patches, dominant; and 5 - thick growth covering the substrate at the exclusion of other species.
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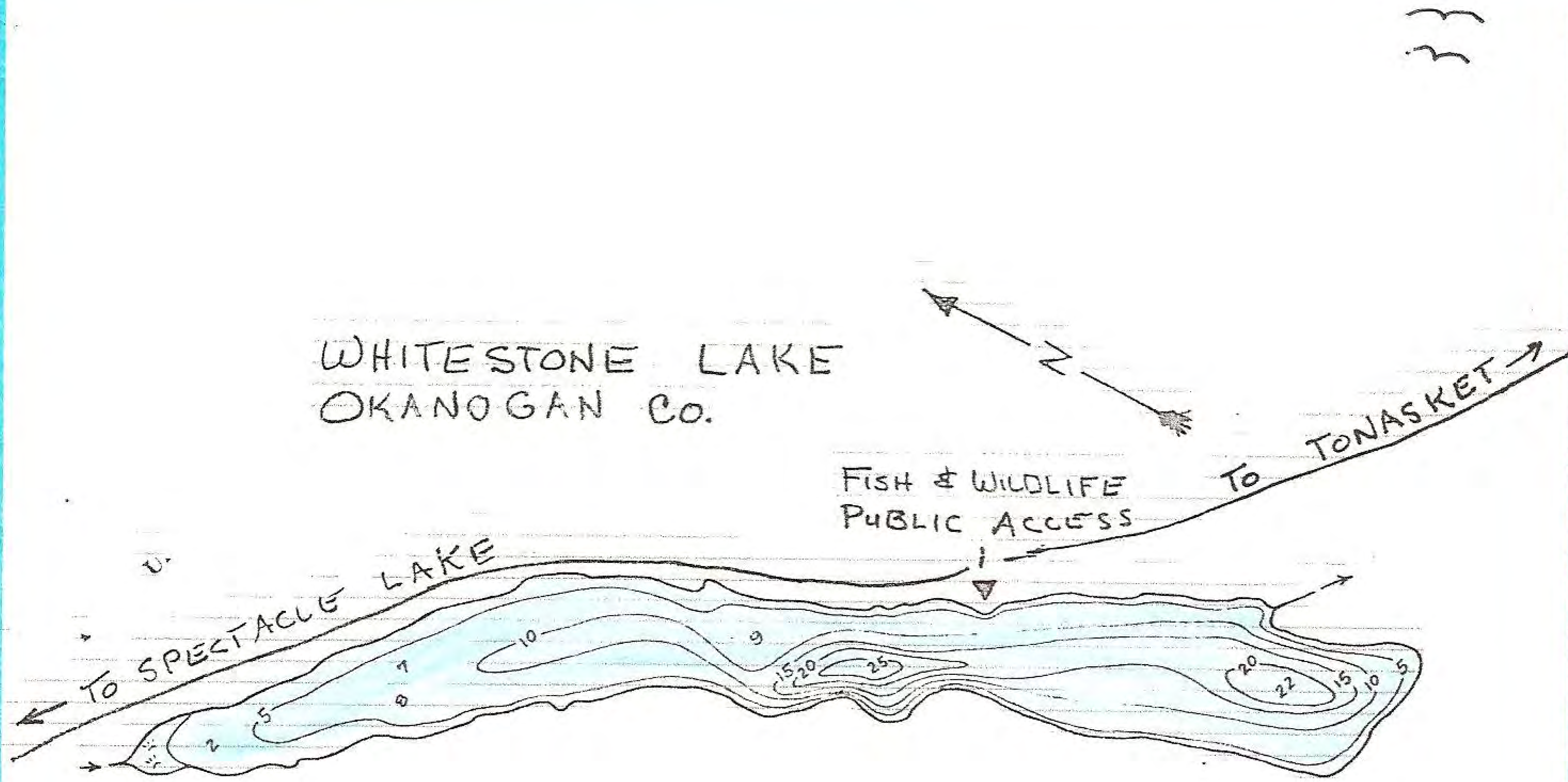
WHITESTONE LAKE
OKANOGAN Co.
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WASHINGTON STATE DEPARTMENT OF
Natural Resources

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Washington Natural Heritage Information System
List of Known Occurrences of Rare Plants in Washington
March 2014

Okanogan County

A key to status fields appears below. If a scientific name is underlined you may click on it to go to a field guide page (pdf format, average size 300 kb) for that taxon.

Scientific Name	Common Name	State Status	Federal Status	Historic Record
Agoseris aurantiaca var. carnea	pink agoseris	S		
Agoseris elata	tall agoseris	S		
Agrostis mertensii	northern bentgrass	T		
Anemone patens var. multifida	pasqueflower	T		
Anthoxanthum hirtum	common northern sweetgrass	R1		
Astragalus robbinsii var. minor	Robbins' milk-vetch	R1		
Botrychium ascendens	triangular-lobed moonwort	S	SC	
Botrychium crenulatum	crenulate moonwort	S	SC	
Botrychium paradoxum	two-spiked moonwort	T	SC	
Bryoerythrophyllum columbianum	Columbian bryoerythrophyllum moss	R1		
Bryum calobryoides	bryum moss	R1		
Buxbaumia aphylla	bug-on-a-stick moss	R1		
Buxbaumia viridis	buxbaumia moss	R1		
Carex atrosquama	blackened sedge	R1		
Carex capillaris	hair-like sedge	T		
Carex capitata	capitate sedge	S		H
Carex chordorrhiza	cordroot sedge	S		
Carex gynocrates	yellow bog sedge	S		
Carex heteroneura var. epapillosa	smooth-fruit sedge	S		
Carex magellanica ssp. irrigua	poor sedge	S		
Carex media	intermediate sedge	S		
Carex proposita	Smoky Mountain sedge	T		
Carex scirpoidea ssp. scirpoidea	Canadian single-spike sedge	S		
Carex sychnocephala	many-headed sedge	S		
Carex tenera var. tenera	quill sedge	T		
Carex tenuiflora	sparse-flowered sedge	T		
Carex vallicola	valley sedge	S		
Carex vernacula	foetid sedge	R1		
Chrysosplenium tetrandrum	northern golden-carpet	S		
Cirsium flodmanii	Flodman's thistle	R1		
Coeloglossum viride	long-bract frog orchid	T		
Comastoma tenellum	slender gentian	S		
Crataegus phippsii	Phipps' hawthorn	R1		

Cryptantha spiculifera	Snake River cryptantha	S	
Cryptogramma stelleri	Steller's rockbrake	S	
Cypripedium parviflorum	yellow lady's-slipper	T	
Draba aurea	golden draba	S	
Draba cana	lance-leaved draba	S	
Eleocharis rostellata	beaked spike-rush	S	
Elodea nuttallii	Nuttall's waterweed	R1	
Erigeron elatus	tall bitter fleabane	E	
Erigeron piperianus	Piper's daisy	S	
Erigeron salishii	Salish fleabane	S	
Eriophorum viridicarinatum	green-keeled cotton-grass	S	
Eritrichium nanum var. elongatum	pale alpine forget-me-not	S	
Erythranthe patula	stalk-leaved monkeyflower	T	
Erythranthe pulsiferae	Pulsifer's monkeyflower	S	
Erythranthe suksdorfii	Suksdorf's monkeyflower	S	
Erythranthe washingtonensis	Washington monkeyflower	X	H
Eurybia merita	Arctic aster	S	
Gentiana glauca	glaucous gentian	S	
Geum rivale	water avens	S	
Helodium blandowii	Blandow's helodium moss	R1	
Herzogiella seligeri	Seliger's herzogiella moss	R1	
Lathrocasis tenerrima	delicate gilia	S	
Luzula arcuata ssp. unalaschkensis	curved woodrush	S	
Meesia triquetra	meesia moss	R1	
Meesia uliginosa	meesia moss	R1	
Monolepis spathulata	prostrate poverty-weed	S	
Orthotrichum hallii	Hall's orthotrichum moss	R1	
Orthotrichum pylaisii	Pylais' orthotrichum moss	R1	
Oxytropis campestris var. columbiana	Columbia crazyweed	E	
Oxytropis campestris var. cusickii	Cusick's crazyweed	R1	
Oxytropis campestris var. gracilis	slender crazyweed	S	
Packera bolanderi var. harfordii	Harford's ragwort	S	H
Parnassia kotzebuei	Kotzebue's grass-of-parnassus	T	
Platanthera aquilonis	Sheviak's bog orchid	R1	H
Platanthera obtusata ssp. obtusata	small northern bog-orchid	S	
Polemonium viscosum	skunk polemonium	S	
Polytrichum strictum	bog haircap moss	R1	
Potamogeton obtusifolius	blunt-leaf pondweed	S	
Potentilla glaucophylla var. perdissecta	diverse-leaved cinquefoil	S	
Potentilla nivea	snow cinquefoil	S	
Ptilium crista-castrensis	knight's plume moss	R1	
Ranunculus pygmaeus	dwarf buttercup	R1	
Rubus arcticus ssp. acaulis	nagoonberry	T	
Salix glauca var. villosa	glaucous willow	S	
Salix maccalliana	Maccall's willow	S	
Salix tweedyi	Tweedy's willow	S	
Sanicula marilandica	black snake-root	S	
Saxifraga cernua	nodding saxifrage	S	
Saxifraga hyperborea	pygmy saxifrage	S	

Schistostega pennata	luminous moss	R1		
Scutellaria angustifolia ssp. micrantha	narrowleaf skullcap	R1		
Silene scouleri ssp. scouleri	Scouler's catchfly	S		H
Sisyrinchium septentrionale	northern blue-eyed grass	S		
Spiranthes diluvialis	Ute ladies' tresses	E	LT	
Spiranthes porrifolia	western ladies' tresses	S		
Stuckenia filiformis ssp. occidentalis	western fineleaf pondweed	R1		
Thelypodium sagittatum ssp. sagittatum	arrow thelypody	S		H
Triglochin palustris	marsh arrowgrass	R1		H
Vaccinium myrtilloides	velvet-leaved blueberry	S		
Viola renifolia	kidney-leaf white violet	S		

Description of Codes

Historic Record:

H indicates most recent sighting in the county is before 1977.

State Status

State Status of plant species is determined by the Washington Natural Heritage Program. Factors considered include abundance, occurrence patterns, vulnerability, threats, existing protection, and taxonomic distinctness.
Values include:
E = Endangered. In danger of becoming extinct or extirpated from Washington.
T = Threatened. Likely to become Endangered in Washington.
S = Sensitive. Vulnerable or declining and could become Endangered or Threatened in the state.
X = Possibly extinct or Extirpated from Washington.
R1 = Review group 1. Of potential concern but needs more field work to assign another rank.
R2 = Review group 2. Of potential concern but with unresolved taxonomic questions.

Federal Status

Federal Status under the U.S. Endangered Species Act(USESA) as published in the Federal Register:
LE = Listed Endangered. In danger of extinction.
LT = Listed Threatened. Likely to become endangered.
PE = Proposed Endangered.
PT = Proposed Threatened.
C = Candidate species. Sufficient information exists to support listing as Endangered or Threatened.
SC = Species of Concern. An unofficial status, the species appears to be in jeopardy, but insufficient information to support listing.

Washington Natural Heritage Program - www.dnr.wa.gov/ResearchScience/Topics/NaturalHeritage/Pages/amp_nh.aspx/ back to top
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Washington Natural Heritage Information System
Known High-Quality or Rare Plant Communities and Wetland Ecosystems of Washington
August 2012
Okanogan County

Scientific Name	Common Name	Historic Record
Abies amabilis / Achlys triphylla Forest	Pacific Silver Fir / Vanillaleaf	H
Abies amabilis Cover Type	Pacific Silver Fir Forest	H
Abies lasiocarpa / Calamagrostis rubescens Forest	Subalpine Fir / Pinegrass	
Abies lasiocarpa / Ledum glandulosum Forest	Subalpine Fir / Glandular Labrador-tea	
Abies lasiocarpa / Rhododendron albiflorum Woodland	Subalpine Fir / Cascade Azalea	
Abies lasiocarpa / Vaccinium scoparium Forest	Subalpine Fir / Grouseberry	
Abies lasiocarpa Cover Type	Subalpine Fir Forest	H
Alnus viridis ssp. sinuata Shrubland [Placeholder]	Sitka Alder	H
Artemisia tridentata ssp. wyomingensis / Hesperostipa comata Shrubland	Wyoming Big Sagebrush / Needle-and-thread	
Artemisia tridentata ssp. wyomingensis / Pseudoroegneria spicata Shrub Herbaceous Vegetation	Wyoming Big Sagebrush / Bluebunch Wheatgrass	
Artemisia tripartita ssp. tripartita / Festuca idahoensis Shrub Herbaceous Vegetation	Threetip Sagebrush / Idaho Fescue	
Artemisia tripartita ssp. tripartita / Hesperostipa comata Shrub Herbaceous Vegetation	Threetip Sagebrush / Needle-and-thread	
Artemisia tripartita ssp. tripartita / Pseudoroegneria spicata Shrub Herbaceous Vegetation	Threetip Sagebrush / Bluebunch Wheatgrass	
Carex Cover Type	Sedge Spp. Grassland	
Carex scopulorum Herbaceous Vegetation	Holm's Rocky Mountain Sedge	
Carex utriculata Herbaceous Vegetation	Northwest Territory Sedge	
Danthonia intermedia Herbaceous Vegetation	Timber Oatgrass	
Dryas octopetala Dwarf-shrub Herbaceous Vegetation	Eight Petal Mountain-avens	
Festuca idahoensis - Eriogonum heracleoides Herbaceous Vegetation	Idaho Fescue - Parsnip-flower Buckwheat	

Hesperostipa comata Cover Type	Needle-and-thread Grassland	
Inland saline Wetland CB	Inland Saline Wetland CB	
Larix lyallii Woodland [Provisional]	Subalpine Larch Community	H
Larix occidentalis Cover Type	Western Larch Forest	H
Picea engelmannii - Abies lasiocarpa Cover Type	Engelmann Spruce - Subalpine Fir Forest	H
Picea engelmannii / Equisetum arvense Forest	Engelmann Spruce / Field Horsetail	
Pinus albicaulis - Abies lasiocarpa Cover Type	White-bark Pine - Subalpine Fir Forest	
Pinus albicaulis Cover Type	White-bark Pine Forest	
Pinus contorta Cover Type	Lodgepole Pine Forest	
Pinus ponderosa - Pseudotsuga menziesii / Pseudoroegneria spicata ssp. inermis Woodland	Ponderosa Pine - Douglas-fir / Bluebunch Wheatgrass	
Pinus ponderosa - Pseudotsuga menziesii / Purshia tridentata Woodland	Ponderosa Pine - Douglas-fir / Bitterbrush	
Pinus ponderosa - Pseudotsuga menziesii Cover Type	Ponderosa Pine - Douglas-fir Forest	H
Pinus ponderosa / Calamagrostis rubescens Forest	Ponderosa Pine / Pinegrass	
Pinus ponderosa / Purshia tridentata Woodland	Ponderosa Pine / Bitterbrush	
Pinus ponderosa Cover Type	Ponderosa Pine Forest	H
Populus tremuloides / Symphoricarpos albus Forest	Quaking Aspen / Common Snowberry	
Populus tremuloides Cover Type	Quaking Aspen Forest	
Pseudoroegneria spicata Cover Type	Bluebunch Wheatgrass Grassland	
Pseudotsuga menziesii / Arctostaphylos uva-ursi - Purshia tridentata Forest	Douglas-fir / Kinikinnick - Bitterbrush	
Pseudotsuga menziesii / Arctostaphylos uva-ursi Cascadian Forest	Douglas-fir / Kinikinnick Cascadian Forest	
Pseudotsuga menziesii / Calamagrostis rubescens Forest	Douglas-fir / Pinegrass	
Pseudotsuga menziesii / Symphoricarpos albus Forest	Douglas-fir / Common Snowberry	
Purshia tridentata / Festuca idahoensis Shrub Herbaceous Vegetation	Bitterbrush / Idaho Fescue	
Purshia tridentata / Hesperostipa comata Shrub Herbaceous Vegetation	Bitterbrush / Needle-and-thread	
Purshia tridentata / Pseudoroegneria spicata Shrub Herbaceous Vegetation	Bitterbrush / Bluebunch Wheatgrass	
Rhus glabra / Pseudoroegneria spicata Shrub Herbaceous Vegetation	Smooth Sumac / Bluebunch Wheatgrass	
Salix drummondiana / Carex scopulorum var. prionophylla Shrubland	Drummond's Willow / Holm's Rocky Mountain Sedge	
Salix planifolia / Carex scopulorum Shrubland	Tea-leaf Willow / Holm's Rocky Mountain Sedge	H
Schoenoplectus maritimus Herbaceous Vegetation	Seacoast Bulrush	

Subalpine Freshwater Wetland EC	Subalpine Freshwater Wetland EC
Subalpine Riparian Wetland EC	Subalpine Riparian Wetland EC

Washington State Species of Concern Lists

Species of Concern in Washington State

Include those species listed as State Endangered, State Threatened, State Sensitive, or State Candidate, as well as species listed or proposed for listing by the U.S. Fish and Wildlife Service or the National Marine Fisheries Service.

Does not include State Monitored Species

Common Name	Scientific Name	Animal Type	Species Status State	Species Status Federal	Mapping Criteria
American white pelican Annual Report	*Pelecanus erythrorhynchos*	Bird	SE	none	B,RSC
Bald eagle Annual Report Status Report	*Haliaeetus leucocephalus*	Bird	SS	FCo	B,RSC,CR
Beller's ground beetle	*Agonum belleri*	Other Insect	SC	none	IO
Black Rockfish	*Sebastes melanops*	Fish	SC	none	IO
Black-backed woodpecker Annual Report	*Picoides arcticus*	Bird	SC	none	B,RI
Black-tailed jackrabbit Annual Report	*Lepus californicus*	Mammal	SC	none	IO
Blue whale Annual Report	*Balaenoptera musculus*	Mammal	SE	FE	IO
Bluegray Taildropper	*Prophysaon coeruleum*	Mollusk	SC	none	none
Bocaccio rockfish	*Sebastes paucispinis*	Fish	SC	FE	IO
Bog idol leaf beetle	*Donacia idola*	Other Insect	SC	none	IO
Brandt's cormorant	*Phalacrocorax penicillatus*	Bird	SC	none	B
Brown pelican Annual Report	*Pelecanus occidentalis*	Bird	SE	FCo	RSC
Brown rockfish	*Sebastes auriculatus*	Fish	SC	none	IO
Bull Trout	*Salvelinus confluentus*	Fish	SC	FT	none
Burrowing owl Annual Report	*Athene cunicularia*	Bird	SC	none	B
California floater	*Anodonta californiensis*	Mollusk	SC	none	IO
California mountain kingsnake	*Lampropeltis zonata*	Reptile	SC	none	IO
Canary Rockfish	*Sebastes pinniger*	Fish	SC	FT	IO
Cascade red fox Annual Report	*Vulpes vulpes cascadensis*	Mammal	SC	none	none
Cascade torrent salamander	*Rhyacotriton cascadae*	Amphibian	SC	none	IO
Cassin's auklet	*Ptychoramphus aleuticus*	Bird	SC	none	B
Cathlamet Pocket Gopher - Mazama	*Thomomys mazama louiei*	Mammal	ST	FCo	IO
China Rockfish	*Sebastes nebulosus*	Fish	SC	none	none
Chinook salmon (Lower Columbia)	*Oncorhynchus tshawytscha*	Fish	SC	FT	none
Chinook salmon (Puget Sound)	*Oncorhynchus tshawytscha*	Fish	SC	FT	none
Chinook salmon (Snake R. Fall)	*Oncorhynchus tshawytscha*	Fish	SC	FT	none
Chinook salmon (Snake R. Sp/Su)	*Oncorhynchus tshawytscha*	Fish	SC	FT	none
Chinook salmon (Upper Columbia Sp)	*Oncorhynchus tshawytscha*	Fish	SC	FE	none
Chinquapin hairstreak	*Habrodais grunus herri*	Butterfly/Moth	SC	none	IO
Chum salmon (Hood Canal Su) Recovery Plan	*Oncorhynchus keta*	Fish	SC	FT	none
Chum salmon (Lower Columbia)	*Oncorhynchus keta*	Fish	SC	FT	none
Clark's grebe Annual Report	*Aechmophorus clarkii*	Bird	SC	none	B
Coho salmon (Lower Columbia/SW WA)	*Oncorhynchus kisutch*	Fish	none	FT	none
Columbia clubtail (dragonfly)	*Gomphus lynnae*	Other Insect	SC	none	IO
Columbia oregonian	*Cryptomastix hendersoni*	Mollusk	SC	none	IO
Columbia pebblesnail	*Fluminicola columbiana*	Mollusk	SC	none	IO
Columbia River tiger beetle	*Cicindela columbica*	Other Insect	SC	none	IO
Columbia spotted frog	*Rana luteiventris*	Amphibian	SC	none	IO
Columbian Sharp-tailed Grouse Annual Report Status Report Recovery Plan	*Tympanuchus phasianellus*	Bird	ST	none	B,RSC
Columbian white-tailed deer Annual Report	*Odocoileus virginianus leucurus*	Mammal	SE	FE	IO
Common loon Annual Report Status Report	*Gavia immer*	Bird	SS	none	B
Common murre	*Uria aalge*	Bird	SC	none	B,RC
Common Sharp-tailed snake	*Contia tenuis*	Reptile	SC	none	IO
Copper Rockfish	*Sebastes caurinus*	Fish	SC	none	IO
Dalle's Sideband	*Monadenia fidelis minor*	Mollusk	SC	none	
Dunn's salamander	*Plethodon dunni*	Amphibian	SC	none	IO
Eulachon	*Thaleichthys pacificus*	Fish	SC	FT	RC
Ferruginous hawk Annual Report Recovery Plan	*Buteo regalis*	Bird	ST	none	B

Fin whale Annual Report	*Balaenoptera physalus*	Mammal	SE	FE	IO
Fisher Annual Report Status Report Recovery Plan	*Martes pennanti*	Mammal	SE	FC	IO
Flammulated owl Annual Report	*Otus flammeolus*	Bird	SC	none	B,RI
Giant Columbia River limpet	*Fisherola nuttalli*	Mollusk	SC	none	IO
Giant Palouse earthworm Annual Report	*Driloleirus americanus*	Annelid	SC	none	IO
Golden eagle Annual Report	*Aquila chrysaetos*	Bird	SC	none	B
Gray whale Annual Report Status Report	*Eschrichtius robustus*	Mammal	SS	none	IO
Gray wolf Annual Report	*Canis lupus*	Mammal	SE	FE	IO
Gray-tailed vole	*Microtus canicaudus*	Mammal	SC	none	IO
Great arctic	*Oeneis nevadensis gigas*	Butterfly/Moth	SC	FCo	IO
Greater Sage-grouse Annual Report Status Report Recovery Plan	*Centrocercus urophasianus*	Bird	ST	FC	B,RSC
Green sea turtle Annual Report	*Chelonia mydas*	Reptile	ST	FT	IO
Green Sturgeon	*Acipenser medirostris*	Fish	none	FT	IO
Greenstriped Rockfish	*Sebastes elongatus*	Fish	SC	none	IO
Grizzly bear Annual Report	*Ursus arctos*	Mammal	SE	FT	IO
Harbor porpoise	*Phocoena phocoena*	Mammal	SC	none	RSC
Hatch's click beetle	*Eanus hatchi*	Other Insect	SC	none	IO
Humpback whale Annual Report	*Megaptera novaeangliae*	Mammal	SE	FE	IO
Island Marble Annual Report	*Euchloe ausonides*	Butterfly/Moth	SC	FCo	none
Johnson's hairstreak	*Mitoura johnsoni*	Butterfly/Moth	SC	none	IO
Juniper hairstreak	*Mitoura grynea barryi*	Butterfly/Moth	SC	none	IO
Keen's myotis Annual Report	*Myotis keenii*	Mammal	SC	none	B,IO
Killer whale Annual Report Status Report	*Orcinus orca*	Mammal	SE	FE	IO
Lake Chub	*Couesius plumbeus*	Fish	SC	none	IO
Larch Mountain salamander Annual Report Status Report	*Plethodon larselli*	Amphibian	SS	none	IO
Leatherback sea turtle Annual Report	*Dermochelys coriacea*	Reptile	SE	FE	IO
Leopard dace	*Rhinichthys falcatus*	Fish	SC	none	IO
Leschi's Millipede	*Leschius mcallisteri*	Arthropod	SC	none	none
Lewis' woodpecker	*Melanerpes lewis*	Bird	SC	none	B
Loggerhead sea turtle Annual Report	*Caretta caretta*	Reptile	ST	FE	IO
Loggerhead shrike Annual Report	*Lanius ludovicianus*	Bird	SC	none	B
Lynx Annual Report Status Report Recovery Plan	*Lynx canadensis*	Mammal	ST	FT	IO
Makah copper	*Lycaena mariposa charlottensis*	Butterfly/Moth	SC	none	none
Mann's Mollusk-eating Ground Beetle	*Scaphinotus mannii*	Other Insect	SC	none	IO
Marbled murrelet Annual Report	*Brachyramphus marmoratus*	Bird	ST	FT	B
Mardon skipper Annual Report Status Report	*Polites mardon*	Butterfly/Moth	SE	FCo	IO
Margined sculpin Annual Report Status Report	*Cottus marginatus*	Fish	SS	none	IO
Mazama (Western) pocket gopher Annual Report Status Report	*Thomomys mazama*	Mammal	ST	none	IO
Merriam's shrew	*Sorex merriami*	Mammal	SC	none	IO
Mountain Sucker	*Catostomus platyrhynchus*	Fish	SC	none	IO
Northern abalone	*Haliotis kamtschatkana*	Mollusk	SC	none	IO
Northern goshawk	*Accipiter gentilis*	Bird	SC	FCo	B
Northern leopard frog Annual Report Status Report	*Rana pipiens*	Amphibian	SE	none	IO
Northern Sea otter	*Enhydra lutris*	Mammal	SE	FCo	B,RI,RSC
Northern Spotted Owl Annual Report	*Strix occidentalis*	Bird	SE	FT	IO
Olympia oyster	*Ostrea lurida*	Mollusk	SC	none	none
Olympia Pocket Gopher - Mazama	*Thomomys mazama pugetensis*	Mammal	ST	FT	none
Olympic marmot Annual Report	*Marmota olympus*	Mammal	SC	none	IO
Olympic mudminnow Annual Report Status Report	*Novumbra hubbsi*	Fish	SS	none	IO
Olympic Pocket Gopher - Mazama	*Thomomys mazama melanops*	Mammal	ST	FCo	IO
Oregon silverspot butterfly Annual Report Status Report	*Speyeria zerene hippolyta*	Butterfly/Moth	SE	FT	IO

Oregon spotted frog Annual Report Status Report Recovery Plan	*Rana pretiosa*	Amphibian	SE	FPT	IO
Oregon vesper sparrow Annual Report	*Pooecetes gramineus affinis*	Bird	SC	none	B
Pacific clubtail	*Gomphus kurilis*	Other Insect	SC	none	IO
Pacific cod (S&C Puget Sound)	*Gadus macrocephalus*	Fish	SC	FCo	IO
Pacific hake (Pacific-Georgia Basin DPS	*Merluccius productus*	Fish	SC	FCo	IO
Pacific Herring	*Clupea pallasi*	Fish	SC	none	none
Peregrine falcon Annual Report Status Report	*Falco peregrinus*	Bird	SS	FCo	B,RI
Pileated woodpecker	*Dryocopus pileatus*	Bird	SC	none	B
Poplar oregonian	*Cryptomastix populi*	Mollusk	SC	none	IO
Preble's shrew	*Sorex preblei*	Mammal	SC	none	IO
Puget blue	*plebejus icarioides blackmorei*	Butterfly/Moth	SC	none	none
Purple martin	*Progne subis*	Bird	SC	none	B
Pygmy rabbit Annual Report Status Report Recovery Plan	*Brachylagus idahoensis*	Mammal	SE	FE	none
Pygmy Whitefish Annual Report Status Report	*Prosopium coulteri*	Fish	SS	none	IO
Quillback Rockfish	*Sebastes maliger*	Fish	SC	none	IO
Redstripe Rockfish	*Sebastes proriger*	Fish	SC	none	IO
River lamprey	*Lampetra ayresi*	Fish	SC	FCo	IO
Rocky Mountain Tailed Frog	*Ascaphus montanus*	Amphibian	SC	none	IO
Roy Prairie Pocket Gopher - Mazama	*Thomomys mazama glacialis*	Mammal	ST	FT	none
Sage thrasher	*Oreoscoptes montanus*	Bird	SC	none	B
Sagebrush lizard	*Sceloporus graciosus*	Reptile	SC	none	IO
Sagebrush Sparrow	*Artemisiospiza nevadensis*	Bird	SC	none	none
Sand-verbena moth	*Copablepharon fuscum*	Butterfly/Moth	SC	none	IO
Sandhill crane Annual Report Recovery Plan	*Grus canadensis*	Bird	SE	none	B,RLC
Shelton pocket gopher - Mazama	*Thomomys mazama couchi*	Mammal	ST	FCo	IO
Shepard's parnassian	*Parnassius clodius shepardi*	Butterfly/Moth	SC	none	IO
Silver-bordered fritillary	*Boloria selene atrocostalis*	Butterfly/Moth	SC	none	none
Slender-billed white-breasted nuthatch Annual Report	*Sitta carolinensis aculeata*	Bird	SC	none	IO
Snowy plover Annual Report	*Charadrius nivosus*	Bird	SE	FT	none
Sockeye salmon (Ozette Lake)	*Oncorhynchus nerka*	Fish	SC	FT	none
Sockeye salmon (Snake R.)	*Oncorhynchus nerka*	Fish	SC	FE	none
Sperm whale Annual Report	*Physeter macrocephalus*	Mammal	SE	FE	IO
Steelhead (Lower Columbia)	*Oncorhynchus mykiss*	Fish	SC	FT	none
Steelhead (Middle Columbia)	*Oncorhynchus mykiss*	Fish	SC	FT	none
Steelhead (Puget Sound)	*Oncorhynchus mykiss*	Fish	none	FT	none
Steelhead (Snake River)	*Oncorhynchus mykiss*	Fish	SC	FT	none
Steelhead (Upper Columbia)	*Oncorhynchus mykiss*	Fish	SC	FT	none
Steller sea lion Annual Report Status Report	*Eumetopias jubatus*	Mammal	ST	FCo	RSC
Streaked horned lark Annual Report Status Report Recovery Plan	*Eremophila alpestris strigata*	Bird	SE	FT	B
Striped whipsnake Annual Report	*Masticophis taeniatus*	Reptile	SC	none	IO
Taylor's checkerspot Annual Report Status Report	*Euphydryas editha taylori*	Butterfly/Moth	SE	FE	IO
Tenino Pocket Gopher - Mazama	*Thomomys mazama tumuli*	Mammal	ST	FT	none
Tiger Rockfish	*Sebastes nigrocinctus*	Fish	SC	none	IO
Townsend's big-eared bat Annual Report Recovery Plan	*Corynorhinus townsendii*	Mammal	SC	none	B,CR
Townsend's ground squirrel Annual Report	*Urocitellus townsendii townsendii*	Mammal	SC	none	none
Tufted puffin Annual Report	*Fratercula cirrhata*	Bird	SC	none	RLC
Umatilla dace	*Rhinichthys umatilla*	Fish	SC	none	IO
Upland sandpiper Annual Report	*Bartramia longicauda*	Bird	SE	none	B,RI
Valley silverspot	*Speyeria zerene bremnerii*	Butterfly/Moth	SC	none	IO
Van Dyke's salamander	*Plethodon vandykei*	Amphibian	SC	none	IO
Vaux's swift Annual Report	*Chaetura vauxi*	Bird	SC	none	B,CR
Walleye pollock (So. Puget Sound)	*Theragra chalcogramma*	Fish	SC	FCo	IO
Washington ground squirrel Annual Report	*Urocitellus washingtoni*	Mammal	SC	FC	none
Western gray squirrel Annual Report Status Report Recovery Plan	*Sciurus griseus*	Mammal	ST	none	IO
Western grebe Annual Report	*Aechmophorus occidentalis*	Bird	SC	none	B
	Actinemys marmorata	Reptile	SE	none	none

Western pond turtle Annual Report Status Report Recovery Plan					
Western toad	*Anaxyrus boreas*	Amphibian	SC	none	none
White-headed woodpecker Annual Report	*Picoides albolarvatus*	Bird	SC	none	B,RI
White-tailed jackrabbit Annual Report	*Lepus townsendii*	Mammal	SC	none	IO
Widow Rockfish	*Sebastes entomelas*	Fish	SC	none	IO
Wolverine Annual Report	*Gulo gulo*	Mammal	SC	FC	IO
Woodland caribou Annual Report	*Rangifer tarandus*	Mammal	SE	FE	IO
Yellow-billed cuckoo Annual Report	*Coccyzus americanus*	Bird	SC	FPT	B,RI
Yelloweye rockfish	*Sebastes ruberrimus*	Fish	SC	FT	IO
Yellowtail Rockfish	*Sebastes flavidus*	Fish	SC	none	IO
Yelm Pocket Gopher - Mazama	*Thomomys mazama yelmensis*	Mammal	ST	FT	IO
Yuma skipper	*Ochlodes yuma*	Butterfly/Moth	SC	none	IO

Biology and Control of Aquatic Plants

A Best Management Practices Handbook: Third Edition

Lyn A. Gettys, William T. Haller and David G. Petty, editors

Aquatic Ecosystem Restoration Foundation

The Aquatic Ecosystem Restoration Foundation views sustainability in the aquatic industry as:

Protecting, rehabilitating and restoring biodiversity while sustaining the health of critical natural aquatic habitats and ecosystems through the selective control or eradication of invasive and nuisance aquatic weeds and algae. Aquatic weeds and nuisance algae alter the ecological balance in bodies of water such as lakes, ponds, rivers, streams and estuaries.

Invasive aquatic and riparian vegetation are significant stressors on our nation's aquatic habitats. The impact on those habitats include decreasing biodiversity, degrading water quality, impeding navigation, irrigation and recreation, impacting the health of animals and humans, and accelerating the loss of habitat for fish and wildlife. Based on sound science, the AERF supports the responsible use of all tools available, including EPA registered aquatic herbicides and algicides. The strategic use of these tools should be employed to return threatened bodies of water to sustainable aquatic ecosystems.

We have a responsibility to create sustainable aquatic ecosystems that will preserve the integrity of these aquatic environments for future generations. This responsibility includes protecting, restoring and enhancing aquatic ecosystems while encouraging the use of sustainable management practices for our nation's waters.

Restoration Regulatory Research

February 2014

Dear Reader:

Thank you for your interest in aquatic plant management. The Aquatic Ecosystem Restoration Foundation (AERF) is pleased to bring you the third edition of *Biology and Control of Aquatic Plants: A Best Management Practices Handbook*.

The mission of the AERF, a not for profit foundation, is to support research and development which provides strategies and techniques for the environmentally and scientifically sound management, conservation and restoration of aquatic ecosystems. One of the ways the Foundation accomplishes the mission is by providing information to the public on the benefits of conserving aquatic ecosystems. The handbook has been one of the most successful ways of distributing information to the public regarding aquatic plant management. The first and second editions of this handbook became some of the most widely read and used references in the aquatic plant management community. This third edition has been specifically designed with the water resource manager, water management association, homeowners and customers and operators of aquatic plant management companies and districts in mind. It is not intended to provide the answers to every question, but it should provide basic scientifically sound information to assist decision-makers.

The authors, editors and contributors reflect the best the aquatic plant management industry has to offer. They gave generously of their time and talent in the production of this document and they deserve all the praise and thanks that can be garnered. Not only have they prepared the chapters and appendices, they are available to all interested parties to provide clarification and additional information as warranted. These scientists, professors, aquatic plant managers and government officials have created a document that surely will be the most widely read and circulated handbook produced to date. Thank you all.

The production of this document has been made possible through the generosity of sponsors of the Foundation. My thanks and appreciation to these faithful supporters who continue to underwrite what has been an effort to provide the very best handbook possible.

I hope you find this handbook to be helpful and informative. A downloadable version is on the AERF website at **www.aquatics.org** along with other useful information and links. Consider becoming a sponsor of the Foundation and supporting educational projects and other ecosystem restoration efforts across the country.

Carlton R. Layne
Executive Director

Restoration Regulatory Research

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Chapter 1: Impact of Invasive Aquatic Plants on Aquatic Biology

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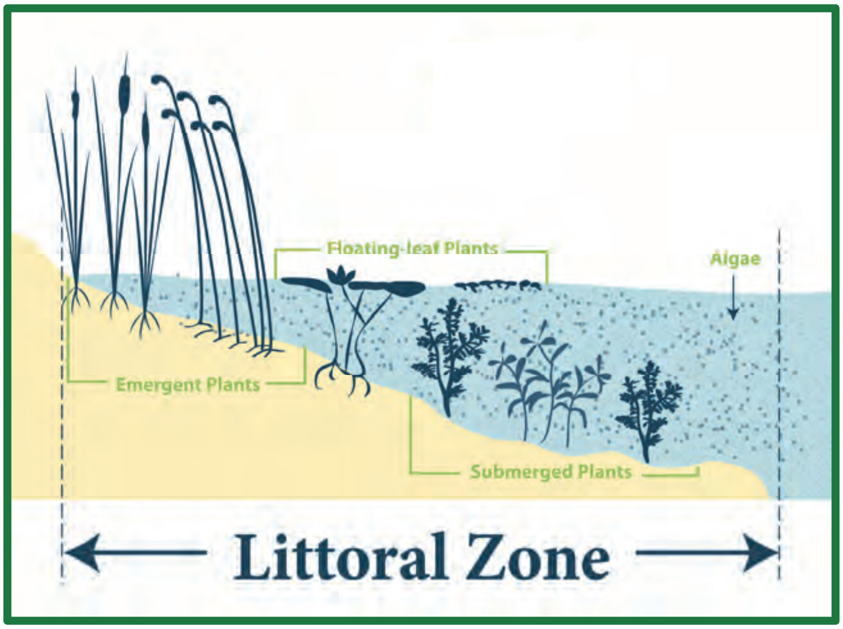
Introduction

Aquatic plants play an important role in aquatic systems worldwide because they provide food and habitat to fish, wildlife and aquatic organisms. Plants stabilize sediments, improve water clarity and add diversity to the shallow areas of lakes. Unfortunately, nonnative plants that are introduced to new habitats often become a nuisance by hindering human uses of water and threaten the structure and function of diverse native aquatic ecosystems. Significant resources are often expended to manage infestations of aquatic weeds because unchecked growth of these invasive species often interferes with use of water, increases the risk of flooding and results in conditions that threaten public health.

Types of aquatic plants

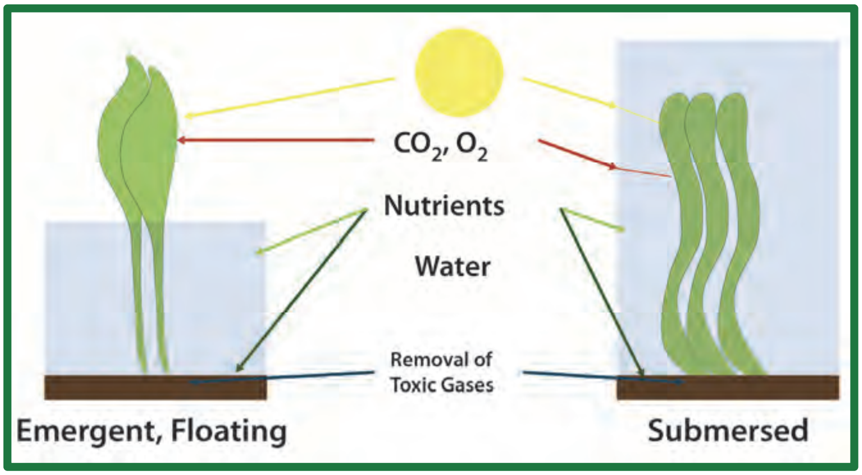
Aquatic plants grow partially or completely in water. Macrophytic plants are large enough to be seen with the naked eye (as compared to phytoplankton, which are tiny and can only be identified with a microscope) and are found in the shallow zones of lakes or rivers. This shallow zone is called the <u>littoral zone</u> and is the area where sufficient light penetrates to the bottom to support the growth of plants. Plants that grow in littoral zones are divided into three groups. <u>Emergent plants</u> inhabit the shallowest water and are rooted in the sediment with their leaves extending above the water's surface. Representative species of emergent plants include bulrush, cattail and arrowhead. <u>Floating-leaved plants</u> grow at intermediate depths. Some floating-leaved species are rooted in the sediment, but others are free-floating with roots that hang unanchored in the water column. The leaves of floating-leaved plants float more or less flat on the surface of the water. Waterlily and spatterdock are floating-leaved species, whereas waterhyacinth (Chapter 15.7) and waterlettuce (Chapter 15.8) are free-floating plants. <u>Submersed plants</u> are rooted in the sediment and inhabit the deepest fringe of the littoral zone where light penetration is sufficient to support growth of the plant. Submersed plants grow up through the water column and the growth of most submersed species occurs entirely within the water column, with no plant parts emerging from the water. Submersed species include hydrilla (Chapter 15.1), curlyleaf pondweed (Chapter 15.3), egeria (Chapter 15.4) and vallisneria.



Algae also grow in lakes and provide the basis of the food chain. The smallest algae are called phytoplankton and are microscopic cells that grow suspended in the water column throughout the lake (Chapter 13). Dense growth of phytoplankton may make water appear green, but even the "cleanest" lake with no green coloration has phytoplankton suspended in the water. Filamentous algae grow as chains of cells and may form large strings or mats. Some filamentous algae are free-floating and grow suspended in the water column, but other species grow attached to plants or the bottom of the lake. Macroscopic or macrophytic algae are large green organisms that look like submersed plants, but are actually algae (Chapter 13).

What aquatic plants need

Plants have simple needs in order to grow and thrive – they require carbon dioxide, oxygen, nutrients, water and light. Plants use light energy, water and carbon dioxide to synthesize carbohydrates and release oxygen into the environment during photosynthesis. Animals use both the carbohydrates and oxygen produced by plants during photosynthesis to survive, so without plants there would be no animal life. The nutrients required in the greatest quantity by plants are nitrogen and phosphorus, but a dozen or more other minerals are also needed to support plant growth. Plant cells use oxygen in the process of respiration just like animal cells, but this is often forgotten since plants produce more oxygen than they need for their own use.



Aquatic plants inhabit an environment very favorable in one respect – most terrestrial plants must find sufficient water to survive. Aquatic plants are literally bathed in water, one of the primary requirements for plant growth. Since aquatic sediments are typically high in nitrogen and phosphorus, life might appear idyllic for aquatic plants. Once the leaves of emergent and floating–leaved plants rise above the water surface, they have a ready supply of carbon dioxide, oxygen and light. In addition, the leaves may act as a conduit for the ready disposal of toxic gases like methane and sulfur dioxide produced in the sediments surrounding plant roots. Given these factors, it is no surprise that emergent plants in fertile marshes are among the most productive ecosystems in the world.

Alas, life is not as easy for submersed plants. While submersed plants have easy access to the same pool of nutrients from the water and the sediment, the availability of light and carbon dioxide is significantly reduced since most submersed plants live completely under the water. Light must penetrate through the water column to reach submersed plants; therefore, much less light energy is available to them. Also, carbon dioxide must be extracted from the water, an environment in which carbon dioxide is present in much lower concentrations and diffuses much more slowly than in the air. As a result, submersed plants are much less productive than emergent and floating plants and the primary factors limiting their growth are the availability of light and carbon dioxide. Some highly productive plants have developed means to increase their access to light and carbon dioxide. For example, species such as hydrilla form dense canopies on the surface of the water, which allows them to capture light energy that is less available near the bottom of the water column. These productive (and often invasive) aquatic plants form dense colonies that interfere with human uses of the littoral areas, increase flooding risk and shade out plants – including most native species – that do not form canopies.

Lake ecology

Trophic state

Trophic state describes the overall productivity (amount of plants or algae) of a lake, which has implications for the biological, chemical and physical conditions of the lake. For example, aquatic animals use plants as a food source, so unproductive lakes do not support large populations of zooplankton, invertebrates, fish, birds, snakes and other animals. The trophic state of a lake is directly tied to the overall algal productivity of the lake and ranges from very unproductive to highly productive. Because phytoplankton typically control lake productivity, factors that increase algal productivity also increase the trophic state of the lake. Algal biomass in a lake is estimated by measuring the concentration of chlorophyll in the water; hence, lake chlorophyll concentration is a direct measure of lake trophic state.

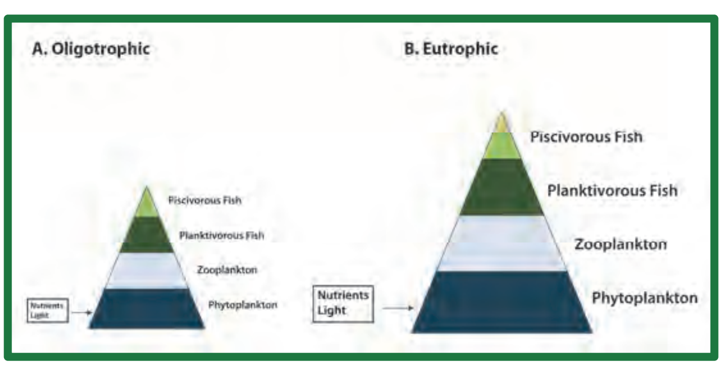
Chlorophyll is directly related to phosphorus concentration in the lake, so phosphorus is also considered a direct measure of lake trophic state. Lake transparency is the most widely measured characteristic to determine trophic state because growth of algae increases water turbidity – high algal growth reduces water clarity, which suggests high productivity. Trophic state can be measured with a Secchi disk because most turbidity in lakes is caused by suspended algae. Since increased algal growth makes the water less transparent, Secchi disk depth is a measure of lake trophic state. Chlorophyll, phosphorus and Secchi disk depth are measured in different units. The Trophic State Index (TSI) employs equations that allow users to develop a single uniform number for trophic state based on any one of the three factors alone or on the average of all three factors (chlorophyll, total phosphorus or Secchi disk depth). This tool is useful to compare trophic state data collected by differing methods and has empowered hundreds of lay monitors to collect trophic state data using only a Secchi disk to estimate water clarity.

Four terms are commonly used to describe lake trophic state. Oligotrophic lakes are unproductive with low nutrients (phosphorus < 15 μg/L) and low algal productivity (chlorophyll < 3 μg/L). Transparency, as measured by the Secchi disk method, is greater than 13 feet. Oligotrophic lakes are typically well-oxygenated and often support cold-water fisheries in the northern US.

Mesotrophic lakes are moderately productive, with intermediate levels of chlorophyll, nutrients and water clarity. Mesotrophic lakes may support abundant populations of rooted aquatic plants and often have cool-water fisheries. Eutrophic lakes are highly productive, with high levels of phosphorus and chlorophyll. Water clarity is low and generally ranges from 3 to 8 feet as measured by the Secchi disk method. Eutrophic lakes may support bass fisheries but rarely have productive open-water fisheries. Hypereutrophic lakes have very high phosphorus and chlorophyll levels and water clarity is usually less than 3 feet. In most cases, hypereutrophic lakes are the result of nutrient loading from human activity in the watershed. Algal growth dominates in the lake and few or no rooted plants are present.

Trophic state	Chlorophyll concentration (µg/L)	Total phosphorus concentration (µg/L)	Water clarity (by Secchi Disk, in feet)	Trophic State Index	Description
Oligotrophic	< 3	<15	>13	<30	Very low productivity Clear water Well oxygenated Few plants and animals
Mesotrophic	3-7	15-25	8-13	40-50	Low to medium productivity Moderately clear water Abundant plant growth
Eutrophic	7-40	25-100	3-8	50-60	Medium to high productivity Fair water clarity Dense plant growth
Hypereutrophic	>40	>100	<3	>70	Very high productivity Poor water clarity Limited submersed plant growth, algae dominate

Studies of sediment cores from lakes across the US have verified that many lakes were naturally mesotrophic or eutrophic before Europeans settled in the US, which conflicts with the assumption that all "pristine" lakes are oligotrophic. The nutrient status or trophic state of lakes that are unaffected by human activity is a function of the watershed and its geology. That being said, human activity that causes nutrient runoff into lakes can shift a lake to a higher trophic state, which alters many biological and chemical attributes of the lake. There are many examples of pollution-degraded lakes, but the water quality of many lakes has improved since the passage of the first Clean Water Act and these lakes are returning to their historic water quality levels due to efforts to restore our waterways.



Productivity in lakes

As mentioned above, algae and macrophytic plants are the basis for lake productivity. Plants take up nutrients, water and carbon dioxide from the environment and use light energy to produce carbohydrates and sugars, with oxygen as a byproduct. Herbivores such as crustaceans and insects consume aquatic plants and use energy from the plants to grow. Forage fish such as minnows and bluegill consume these herbivores and use energy from the herbivores to grow. Fish-eating fish such as trout, bass, pike and walleye eat these forage fish and use energy from the forage species to grow (Chapter 2). Because each level of this feeding system is based on the energy of the level below it, this system is often described as a food pyramid. Oligotrophic lakes with few nutrients and little plant production have small pyramids, whereas eutrophic lakes with much higher nutrient concentrations, more total plant growth (algae and rooted plants) and more fish have larger pyramids. This relationship has been recognized by the aquaculture industry and fertilizer is frequently added to production ponds to increase fisheries productivity. However, changes in water quality can increase populations of undesirable fish as well as populations of more desirable species in reservoirs and in natural systems.

Food chains in lakes

A food chain is a depiction of what various organisms in an ecosystem consume. Food chains begin with algae and plants, which are followed by herbivores, small forage fish and finally by the top-level predator. There may be a hundred species in a lake, so the food chain is often simplified to include only the dominant species. Phytoplankton form the base of the food chain in a typical pelagic (open-water) zone. Phytoplankton are consumed by zooplankton (small crustaceans) that are suspended in the water. Zooplankton are in turn eaten by smaller fish such as yellow perch. Yellow perch are then consumed by the top predator such as walleye.

The food chain in the littoral zone is different. Some algae are present – both as phytoplankton and as algae growing on plant surfaces – but much of the food is derived from macrophytic plants. Most macrophytes are consumed only after they have died and partially decomposed into detritus. Detritus is eaten primarily by aquatic insects, invertebrates and larger crustaceans. These detritivores, which live on or near the lake bottom, are in turn consumed by the dominant littoral forage fish such as bluegill sunfish. Lastly, forage fish are consumed by the top predator such as largemouth bass.

Littoral and cold-water pelagic zone food chains are often isolated from each other and almost function as two separate ecosystems within the same lake. The substantial changes caused by shifts between these food chains are exemplified by the history of Lake St. Clair in Michigan. Lake St. Clair only looks small compared to the Great Lakes it lays between – Lakes Huron and Erie. In fact, it is a 430 square mile lake with a maximum depth of 30 feet, although over 90% of the lake is 12 feet deep or less. This shallow lake was very turbid before 1970, with a Secchi disk transparency of only 4 feet. Rooted plants grew in about 20% of the lake and Lake St. Clair was home to a world-class commercial and recreational open-water walleye and yellow perch fishery. Lake St. Clair was invaded in the 1980s by the zebra mussel, an invasive bivalve (clam) that filters water by consuming suspended phytoplankton and the nutrients associated with them. Zebra mussels filtered the water of Lake St. Clair so effectively that water transparency more than doubled a few years after their invasion. Rooted plants expanded to almost 80% of the lake due to increased light penetration and the fishery completely changed. Walleye and yellow perch can still be found, but the former open-water fishery is now used largely for recreational angling for largemouth bass, a typical littoral zone predator.

Aquatic plant communities

Native aquatic plant species tend to separate into depth zone bands (referred to as depth zonation), with a mix of species found in each depth zone. Submersed plants may be found in water as deep as 30 feet or more in oligotrophic lakes and distinct bands of vegetation are visible to the shoreline. Plants in oligotrophic lakes are adapted to low levels of nutrients and carbon dioxide. Light penetrates easily to 30 feet or more and light levels are not limiting, but plants are typically very short. Submersed aquatic mosses also grow at water depths of up to 200 feet in Crater Lake in Oregon. Plant diversity is often relatively low and native plants in oligotrophic lakes rarely form populations that are substantial enough to cause problems.

Depth zonation in mesotrophic lakes is likewise pronounced, with submersed plants growing in water as deep as 15 to 20 feet. Submersed plants may grow to reach the surface of the water, but this growth is typically localized and occurs in water that is less than 10 feet deep. Plant species diversity is usually at a maximum in mesotrophic lakes; numerous plant growth forms are present and result in a multilayered plant canopy. Light penetration may limit plant growth but plants grow at depths greater than in eutrophic lakes and the total amount of plant growth in mesotrophic lakes is often as high as in eutrophic systems. Nutrients rarely limit plant growth in mesotrophic systems and growth of aquatic species is almost completely dependent on light penetration. Residents living next to reservoirs and lakes often report changes in plant coverage from year to year; these changes are typical of dynamic mesotrophic systems and are usually the result of changes in light penetration.

Depth zonation in eutrophic lakes is much less pronounced, with plant growth typically occurring at maximum depths of only 12 to 15 feet. Plant abundance is high, but plant diversity is much lower than in mesotrophic lakes and erect and canopy-forming plants predominate because light is often limited due to growth of phytoplankton. Native plants often produce populations that are large enough to be nuisances, particularly in high-use areas such as boat ramps and swimming areas. Light strongly limits plant growth and canopy-forming plants have a distinct advantage over plants that do not form canopies.

Hypereutrophic lakes typically have poorly developed aquatic plant communities and plants rarely grow in water more than 6 feet deep. Some emergent and floating plants can be found, but submersed plant growth is greatly reduced and typically only canopy-forming species are able to establish. Plants that are able to colonize hypereutrophic lakes often grow to nuisance levels. High algal production results in dense blooms that intercept available light. As a result, plant diversity is low and the abundance of rooted plants is typically lower than in eutrophic lakes.

So what should a typical lake look like? Well, that depends. Without human-mediated nutrient loading from sewage treatment plants and runoff from fields and residential areas, hypereutrophic lakes would be rare occurrences. Therefore, the natural state of a typical lake would include a littoral zone dominated by aquatic plants. Even in eutrophic lakes, nuisance populations of native plants would likely be localized and would cause problems only when the plants interfere with recreational or other uses. However, the introduction of invasive exotic plants changes this dynamic, even in oligotrophic lakes.

Invasive plants

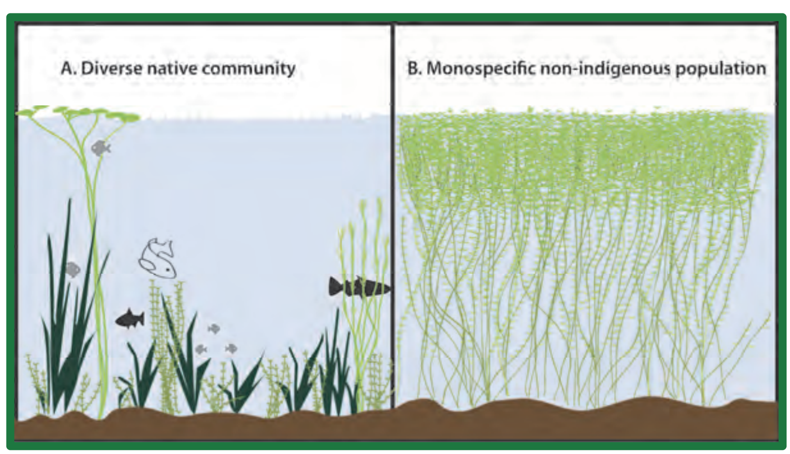
Invasive aquatic plants are generally defined as nonnative (from another geographic region, usually another continent) plant species that cause ecological and/or economic harm to a natural or managed ecosystem. Invasive aquatic plants often cause both economic and ecological harm.

As invasive plants expand in a new area, they suppress the growth of native plants and cause localized extinction of native species. For instance, when Eurasian watermilfoil (Chapter 15.2) invaded Lake George in New York, growth of this exotic species reduced the total number of species in a permanent research plot from 21 to 9 over a three-year period. Invasive plant species can invade a particular zone of the depth profile and suppress the native plant species that normally inhabit the area. Colonization by invasive species may be less damaging in oligotrophic lakes, because native plants can grow at much greater depths than invasive species. Native plants often persist in areas of mesotrophic lakes that are shallower and deeper than those colonized by invasive plants. Invasive plants dominate to the borders of eutrophic and hypereutrophic lakes, with native plants often confined to a shallow fringe around the lake.

Economic impacts	Ecological effects
Impair commercial navigation	Degrade water quality
Disrupt hydropower generation	Reduce species diversity
Increase flood frequency, duration and intensity	Suppress desirable native plants
Impair drinking water (taste and odor)	Increase extinction rate of rare, threatened and endangered species
Habitat for insect-borne disease vectors	Alter animal community interactions
Recreational navigation impairment	Increase detritus buildup
Interfere with safe swimming	Change sediment chemistry
Interfere with fishing	
Reduce property value	
Endanger human health, increase drowning risk	

Summary

Invasive plants reduce native plant growth and impede human uses of waters by forming dense surface canopies that shade out lower-growing native plants and interfere with water flow, boat traffic and fishing. Dense surface canopies also radically change the habitat quality for fish. Dense plant beds provide a place for small forage fish to hide and reduce the ability of predatory fish such as bass and northern pike to see their prey. This tends to lead to a large number of small, stunted forage fishes and poor production of game fishes (Chapter 2).



Invasive plants also reduce water quality. While the increased biomass and dense canopies formed by invasive species tend to increase water clarity, they also lead to increased organic sedimentation. The fate of all lakes over geological time is to progress from lakes to wetlands to marshes to upland areas as lakes fill with sediments due to erosion and accumulation of organic matter. Exotic plants are also significantly more productive than native species and increase the rate of nutrient loading in the system by utilizing nitrogen and phosphorus from the sediment. For example, curlyleaf pondweed has been implicated in increased internal nutrient loading in Midwestern lakes because the plants absorb nutrients from the sediments and grow throughout the spring and summer, then die and release the nutrients into the water. Water also becomes stagnant under dense plant canopies and suppresses or prevents oxygen recirculation. In addition, the amount of dissolved oxygen under dense plant canopies may be insufficient to support desirable fish species and may result in fish kills.

Many animal species are linked to specific native plant communities and the diversity of native communities provides a variety of habitats for aquatic insects and other fauna. Invasive plants reduce the diversity of native plant communities, which leads to a reduction in the diversity of both fish and aquatic insects. Therefore, invasive plants are harmful to the diversity and function of aquatic ecosystems and can have significant adverse impacts on water resources.

For more information:

•Plant growth form definition: http://www.dnr.state.mn.us/shorelandmgmt/apg/wheregrow.html
•Lake productivity: http://www.ecy.wa.gov/Programs/wq/plants/management/joysmanual/lakedata.html
•Lake food chains: http://www.waterontheweb.org/under/lakeecology/11_foodweb.html
•Lake trophic state: http://aquat1.ifas.ufl.edu/guide/trophstate.html;
http://lakewatch.ifas.ufl.edu/circpdffolder/trophic2.pdf
•Secchi disk: http://dipin.kent.edu/secchi.htm; http://www.epa.gov/volunteer/lake/lakevolman.pdf
•Lake TSI (trophic state index): http://dipin.kent.edu/tsi.htm
•Depth zonation of aquatic plants
http://www.niwa.co.nz/news-and-publications/publications/all/wa/10-1/submerged
•Invasive aquatic plants: http://aquat1.ifas.ufl.edu;
http://www.dnr.state.mn.us/invasives/aquaticplants/index.html

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Page 3: Secchi disk; Margaret Glenn, University of Florida Center for Aquatic and Invasive Plants
Page 4: Food pyramids; John Madsen, Mississippi State University Geosystems Research Institute
Page 7: Heterogeneous and homogeneous plant communities; Robert Doyle, Baylor University

Chapter 2: Impact of Invasive Aquatic Plants on Fish

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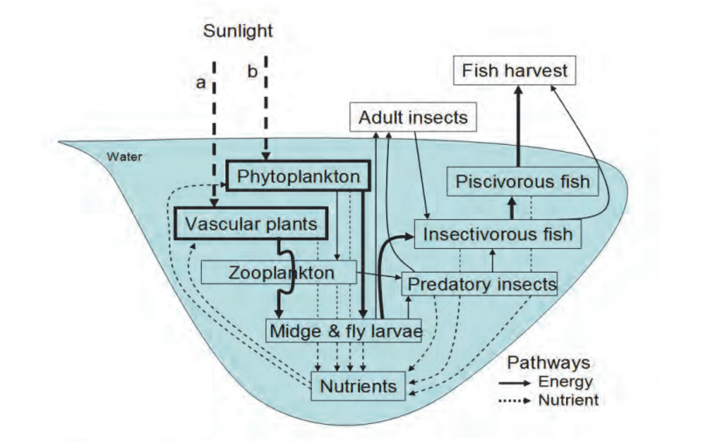
Introduction

Many species of fish rely on aquatic plants at some point during their lives and often move to different habitats based on their growth stage. Young fish use the cover provided by aquatic vegetation to hide from predators and their diets may be dependent on algae and the microfauna (e.g., zooplankton, insects and larvae) that live on aquatic plants. Mature fish of some species move to more open waters to reduce foraging competition and also include other fish in their diets. Also, different fish prefer different types of habitats and will move to a new area if foraging conditions in their preferred location decline due to excessive growth of aquatic weeds.

The energy cycle

The energy that supports all life on earth – including life in lakes – originates from sunlight. Vascular plants and phytoplankton (algae) capture light in the chloroplasts of their cells and convert it to energy through photosynthesis. Aquatic plants and phytoplankton use this energy to subsidize new growth, which is consumed and used as an energy source by aquatic fauna. For example, phytoplankton is eaten by zooplankton or vascular plant tissue is eaten by insect larvae. The zooplankton and insect larvae are then eaten by larger insects and/or insect-eating fish. This energy cycle continues with ever-larger organisms consuming smaller ones and provides a vivid illustration of the "trickle-up economics" of energy cycling. As this example demonstrates, the vegetated aquatic habitat that is essential for insects and small fish can be a critical component in the process that fosters growth of harvestable fish.



Modified after: Horne and Goldman 1994

The relationship between fish and aquatic plants

The abundance of some fish declines with increased plant densities. For example, populations of white bass (*Morone chrysops*), gizzard shad (*Dorosomoa cepedianum*) and inland silverside (*Menidia beryllina*) generally decline where heavy vegetation is present. In contrast, many juvenile and some adult fish prefer habitats with aquatic vegetation; in fact, over 120 different species representing 19 fish families have been collected in aquatic plant beds. Sites with vegetation generally have higher numbers of fish compared to non-vegetated areas. In fact, densities of greater than 1 million fish per acre have been reported in areas containing a diversity of aquatic plants. Very few of these fish, however, survive to become large adults, so high numbers of small fish do not always result in populations of large mature fish. Excessive growth of aquatic plants promotes high populations of small fish in contrast to more diverse and balanced plant populations. Reduced plant densities due to weed management activities, boat traffic and/or natural senescence may change or cause the loss of invertebrate food sources. However, studies of lakes where invasive plants were treated with early applications of herbicides to allow native plants to reestablish have revealed that removal of exotic weeds has little impact on invertebrate populations and no measurable effect on fish communities.

Fish and their affinity for plants

Fish	Plant affinity	Life stage			Relationship		
		Larvae	Juvenile	Adult	Spawn	Forage	Predator avoidance
Bluegill sunfish	High	X	X	X	X	X	X
Common carp	High	X	X	X	X	X	X
Largemouth bass	High	X	X	X	X	X	X
Musky	High	X	X	X	X	X	X
Northern pike	High	X	X	X	X	X	X
Black crappie	Moderate		X	X	X	X	X
Smallmouth bass	Moderate		X	X		X	X
Yellow perch	Moderate	X	X			X	X
White crappie	Low		X			X	
Salmon, trout	Low		X				X
Shad	Low	X					
Walleye	Low			X		X	

Bluegill sunfish (*Lepomis macrochirus*) are often referred to as the "kings" of plant-loving fishes and strongly prefer vegetated habitats throughout much of their lives. There are many different types of small sunfishes, but the bluegill is likely one of the most popular freshwater fish in North America. The bluegill is the most intensely studied freshwater fish in the US and is considered to be a "lab rat" by fish biologists. In addition to its popularity with scientists, the bluegill has been widely stocked, carefully managed and regularly harvested in natural and artificial systems throughout the US. Bluegill is a premier food fish and is called "pan fish" in the North and "bream" in the South.

Similar to other sunfishes, bluegill often move to new habitats as they age. Bluegill sunfish spawn and nest in colonies near areas of submersed vegetation, where soft sediment and plants are cleared. Bluegill larvae are transparent and can safely move from shallow shoreline habitats to open water where they feed on plankton. As the larvae grow larger and develop color, they become more attractive to predators and seek refuge among aquatic vegetation where they feed on insects, midges and small crustaceans. Juveniles and small adult fish remain among shoreline plants and feed on the food they can capture; as they grow, they may shift to feeding on larger crustaceans, insects and amphipods. As fish mature, grow larger and change color, their chances of being eaten by predators decrease and they shift to more optimal feeding grounds. Bluegill continue to feed in vegetated habitats where they can avoid larger predators until they reach approximately 8″ in length. Fish of this size are large enough to escape most of the risk of predation, so these mature bluegill will venture away from the complex structure provided by plants and move to feed in open water. This reduces feeding competition among bluegill and provides access to larger fish that bluegill consume to supply the energy needed for continued growth. Bluegill are not considered herbivores, but they do consume plant material, most likely by accident as they forage for insects and crustaceans living on aquatic plants. Aquatic plants thus play a critical role in the growth of bluegill sunfish by hosting insects, crustaceans and invertebrates that are eaten by young fish and by providing cover that allows young fish to hide from predators.

Fish populations in lakes with a diverse assemblage of phytoplankton, aquatic plants and habitats tend to be stable. This is a general ecological principle that applies to wildlife, fish and other organisms. However, the bluegill sunfish illustrates why it is unwise to make specific "ironclad" statements regarding the habitat requirements of fish. As noted above, bluegill sunfish have very close associations with aquatic plants but can also become quite large and develop robust populations in managed fish ponds that lack aquatic plants. This apparent conflict is partially explained by the concept that bluegill food webs may be based more on phytoplankton where the predator-prey relationship has been simplified.

Largemouth bass (*Micropterus salmoides*) are stocked throughout the world and are among the world's top freshwater game fishes. Largemouth bass are plant-loving and are closely associated with aquatic plants, spending much of their lives in or around vegetated habitats. Adult largemouth bass diligently protect their nests and offspring from predators. The structure provided by moderate densities of submersed plants improves nesting success, but an overabundance of plants can reduce nesting success. Larvae of largemouth bass feed mostly on microcrustaceans and juveniles consume larger (but still small) crustaceans, whereas mature largemouth bass primarily eat aquatic insects and small fishes (e.g., bluegill, shad and silverside). Aquatic plants serve as critical habitats that support the prey that largemouth bass rely so heavily on through their lives. These prey resources directly or indirectly influence growth and the ability of largemouth bass to overwinter and survive adverse conditions. Therefore, the abundance of largemouth bass is strongly correlated with the abundance of submersed vegetation in its habitat. However, this correlation varies based on the types and densities of the plant species in the habitat.

Smallmouth bass (*Micropterus dolomieu*) prefer deeper, cooler waters with rocks and/or woody cover and generally avoid shallow water that is dominated by aquatic plants. However, like the largemouth bass, young smallmouth bass prey on the insects, crustaceans and other microfauna that are hosted by aquatic plants. More mature smallmouth bass consume crayfish, larger insects and other fishes (including shad). Shad feed primarily on phytoplankton and detritus and avoid aquatic vegetation, so the diet of adult smallmouth and largemouth bass may be dependent on prey fish that do not prefer a vegetated habitat, especially in reservoirs. Smallmouth bass protect their nests and offspring but are less selective of nesting location and will choose nesting sites in shallow water if the water has some form of cover. This cover may be provided by aquatic plants, but most sites have cover in the form of rocky outcrops or overhanging woody debris. Because young smallmouth bass consume microfauna associated with aquatic plants and sometimes use aquatic plants to avoid predators, their relationship with aquatic plants is moderate.

White crappie (*Pomoxis annularis*) have a low affinity for aquatic plants as they typically spawn in nests away from vegetation and spend much of their time as adults and juveniles in open water. However, aquatic plants can directly affect spawning and indirectly influence the diet available to young white crappie. Research suggests that excessive amounts of aquatic plants may reduce spawning success of a nesting colony of white crappie. In addition, the presence of aquatic plants may deter nesting altogether. Eggs of white crappie have been found in aquatic vegetation; however, this is most likely incidental drift of eggs from nearby nesting sites. Larval white crappie feed primarily on microfauna, whereas juveniles feed on insect adults and larvae (i.e., midges and water boatmen) that frequently inhabit vegetated habitats.

Black crappie (*Pomoxis nigromaculatus*) are more closely associated with aquatic plants than their cousins, the white crappie, and have a moderate affinity for plants. Adult black crappie prefer sites with plants – including submersed, emergent, flooded and even inundated terrestrial species – for nesting and spawning and are more likely than white crappie to care for nests and offspring. Like white crappie, they also rely on many of the insects that live in aquatic vegetation. In fact, young black crappie rely heavily on insect larvae and other microfauna that are strongly associated with vegetated habitats.

Gizzard shad (*Dorosoma cepedianum*) are small fish that are widely distributed and are frequently stocked in reservoirs as prey for fish-eating fishes such as crappie and striped, largemouth and other bass. Gizzard shad are not usually considered to be associated with aquatic plants; as larvae, they may rely on food resources from vegetated habitats but their affinity for these habitats is low. Larvae of gizzard shad feed on algae, protozoans and microfauna, whereas adults are more herbivorous and consume phytoplankton in the water column and detritus (decomposed vascular plants) in the sediment. Gizzard shad usually spawn at or near the surface of the water and broadcast their eggs. Eggs drift on the water and can attach to any surface, but it is not uncommon to find egg masses attached to aquatic vegetation. In fact, some egg masses are so large that stems of emergent aquatic plants may collapse under their weight.

Common carp (*Cyprinus carpio*) are invasive, exotic, nuisance species that are detrimental to many aquatic systems. Common carp are frequently found in reservoirs and natural lakes and are associated with shallow areas that have soft sediments and abundant submersed vegetation.

Common carp are omnivorous bottom feeders whose diets are composed primarily of organic detritus (mostly in the form of dead plant material) and benthic organisms, including insect adults and larvae, crustaceans, snails, clams and almost anything else organic that they encounter. The mouth parts of common carp are specialized for foraging for hard items (i.e., plants and animals) within soft sediments and among the roots of aquatic plants. Adult fish typically spawn in shallow water inhabited by aquatic plants, where plant stems and leaves serve as attachment sites for fertilized eggs after spawning. Eggs require oxygen to survive; egg attachment to plant structures prevents eggs from settling into soft sediments that lack the oxygen needed for egg survival.

Salmon and **Trout** are not usually associated with aquatic plants and their affinity for vegetated habitats is typically thought to be low. However, some trout species may develop indirect relationships to aquatic plant habitats after the fish are introduced into cool reservoirs and natural lakes. For example, the diet of trout in these systems is often dominated by adults, nymphs and larvae of caddisfly, stonefly, cranefly and mayfly, all insects that are frequently associated with aquatic vegetation. This observation, along with reports that navigation and migration of adult salmon and trout may be hindered by dense beds of invasive aquatic plants, suggests that the relationship of salmon and trout to aquatic vegetation may be complex.

Northern Pike (*Esox lucius*). Aquatic plants play an important role in the foraging and reproductive strategies of northern pike, which typically avoid strong currents and have strong affinities for dense beds of aquatic plants during feeding and spawning. Northern pike primarily feed on other fish by using "ambush" foraging strategies—they wait and strike at prey with a burst of swimming energy. Northern pike are among the first fish to spawn in early spring and broadcast their adhesive-coated eggs on shallow weedy areas. After being released, the eggs drift and settle on submerged vegetation, where they attach and are well-oxygenated.

Muskellunge or **Muskie** (*Esox masquinongy*) are rarely found far from aquatic plants during any stage of their life. They rely heavily on prey resources (i.e., fish, young ducks, frogs and muskrats) that live in vegetated habitats. Muskie spawn later than northern pike, but utilize similar spawning tactics and rely on plants to successfully reproduce. Eggs of muskie also have an adhesive coating and adhere to plant structures after being broadcast.

Walleye (*Stizostedion vitreum*) are not classified as having a strong affinity for aquatic vegetation, despite reports that walleye are sometimes caught near vegetation. However, vegetation in flooded marshes can provide a substrate for spawning, and populations of some species used by walleye as prey (e.g., yellow perch) do rely on vegetated habitats. Walleye are not tolerant of increases in turbidity or suspended sediment. Therefore, aquatic plants may play an indirect role in improving the walleye habitat in some systems by filtering sediments and decreasing water turbidity.

Adults of **Yellow Perch** (*Perca flavescens*) are typically found in open waters with moderate levels of aquatic plants, but when young their affinity for plants is relatively high. Yellow perch are frequently associated with rooted aquatic vegetation. Successful spawning sites typically contain some form of structure, most often in the form of submerged aquatic plants. Like bluegill, young yellow perch switch habitats as they mature. As clear larvae, they feed in open water on zooplankton; once they become pigmented, they return to shallow water with vegetation where they feed on small fishes and insects along the bottom.

Plants provide critical structure to aquatic habitats

The shade created by leafy plants is important to many visual feeders because shade can improve visibility for both selecting prey and avoiding predators. Vegetated aquatic habitats also provide food for young and small fish of many species while protecting them from predators. The abundance and diversity of aquatic fauna eaten by small fish are higher in vegetated habitats than in areas with no plants because leaves and stems provide a surface for attachment; also, small gaps among plants can provide a place for fauna to escape and hide from predators. As vegetated habitats become more complex, the risk of small fish becoming prey may be decreased. However, the ability of fish to forage declines as vegetated habitats become more complex as well. Visual barriers created by leaves and stems may make it more difficult for fish to find and capture prey, whereas swimming barriers that result from dense vegetation can increase search time by reducing maneuverability and swimming velocity. For example, the rate at which sunfish successfully capture prey declines with an increase in structurally complex vegetated habitats. Some fish have developed tactics to address the negative aspects (i.e., reduced food availability accompanied by increased efforts to capture prey) associated with densely vegetated areas. The largemouth bass, for example, changes foraging tactics in complex habitats and switches from actively pursuing prey to ambushing them as they drift or swim by.

Plants influence growth of fish

Studies have shown that aquatic plant abundance affects the growth and health of fish, especially plant-loving fish such as the sunfishes. Habitats with moderate amounts of aquatic vegetation provide the optimal environment for many fish and enhance fish diversity, feeding, growth and reproduction. Conversely, both limited and excessive plant growth may decrease fish growth rates.

High densities of plants can reduce the growth and health of largemouth bass and of black and white crappie, most likely by reducing foraging efficiency. Fisheries scientists have predicted that largemouth bass growth significantly declines in systems with > 40% coverage of aquatic plants and that maintaining plant beds at an average standing crop of 5 tons of fresh weight per acre (4 ounces per square foot) would improve foraging efficiency of largemouth bass. A total removal of plant biomass exposes forage fish and can, at least temporarily, increase growth of predator fish species (i.e., largemouth bass, black and white crappie, bluegill and other sunfishes) that rely heavily on the prey that inhabits vegetated habitats.

Rapid removal of aquatic plants can alter foraging behaviors and encourage young largemouth bass to switch to eating fish sooner in life, which results in more rapid growth. Conversely, young sunfish grow most quickly in vegetated habitats because when plants are absent or sparse, competition for forage sources increases among these fish; less food resources are available to them and growth slows. However, growth of these fish can also be slowed when plant density is too high, especially in shallow-water areas where plants form monotypic beds.

Plants influence spawning

Studies suggest that the structure provided by plant beds is important to fish reproduction. In fact, many fish in North America are "obligate plant spawners" that directly or indirectly require aquatic plants in order to successfully reproduce. At least a dozen fish families use vegetation as nurseries for their young and reproductive success of nest spawners is improved when they have access to sites with aquatic vegetation and/or some form of structure. Fish can derive a number of benefits from nesting near aquatic plants. For example, vegetation can protect nest sites from wave action and sedimentation that can harm eggs and small fish. Also, parents often use aquatic plant patches or edges as "backing" to protect nests from predators. In addition, many fish that live among aquatic plants are visual feeders and the shade produced by overhanging leaves and plant canopies improves visual acuity so fish can find prey – and avoid becoming prey – with greater success. The shallow areas preferred for spawning by nesting fish are not static and can change over time so that a formerly ideal nesting site can become less than perfect. These areas can become overgrown with aquatic plants, which can hinder optimal spawning. Also, nesting fish can change the composition of the littoral zone by disturbing or altering plant growth, which could affect future nesting success.

Plants influence the physical environment

Aquatic plants can change water temperatures and available oxygen in habitats, thus indirectly influencing growth and survival of fish. The amount of oxygen a fish uses during the course of a day is referred to as daily oxygen consumption rate. High numbers of large fish are not usually found in warm-water habitats that are low in dissolved oxygen because larger fish in warmer water need more oxygen; however, smaller fish are more tolerant of such conditions. Shallow areas where aquatic plants are present and water temperatures increase quickly are inhabited by small fish more frequently than large fish because small fish have lower oxygen consumption rates and can tolerate the reduced oxygen available in these habitats. Dense monotypic beds of weeds in shallow-water habitats can negatively impact fish habitats. The structure resulting from dense growth of stems and leaves can interfere with water circulation and surface exchange of atmospheric oxygen, resulting in high water temperatures and low dissolved oxygen. These conditions can seriously impact fish health; in fact, it is not uncommon to have localized fish kills in areas with extremely dense aquatic weeds. Dense plant beds sometimes have relatively open areas that allow water circulation and oxygen exchange to occur. These areas are usually temporary, but they can serve as important refuges for fish during periods when oxygen levels are low in the rest of the weed bed. Plant beds that are managed for fish habitats should include open areas such as patches and/or lanes to improve the water circulation and oxygen exchange that are important to fish health.

The "perfect" lake: artificial and natural systems

Before determining the optimal amount and type of aquatic plants needed to create "perfect" conditions for fish growth, it is important to recognize that the two types of water systems – artificial and natural – differ from one another and present different challenges for management of aquatic plants. Both types of system can be found throughout the US; as a result, the species of fish that inhabit them (and angler goals) vary by location and contribute to management challenges. As noted above, most fish require some sort of structural habitat at some point in their lives. A diversity of structures provides a diversity of habitats, which can support many different types of aquatic organisms, including numerous species of fish. Therefore, a critical goal in managing artificial and natural water systems should be the maintenance of diverse habitats within the littoral zone, which can be accomplished by ensuring that a variety of plant species are available.

Reservoirs

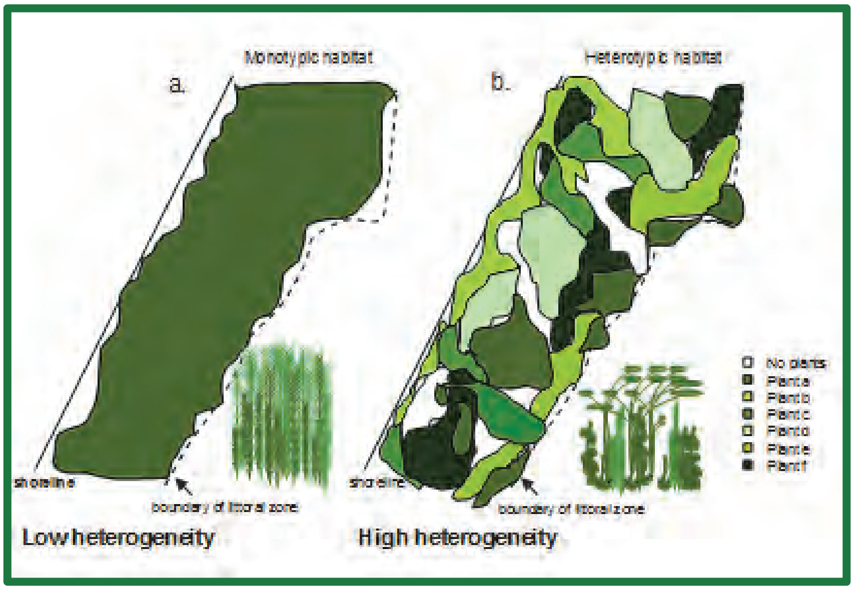
Reservoirs are typically young (< 100 years old) artificial systems constructed to prevent flooding, generate electrical power and/or to provide navigation for barge traffic. Much of a reservoir is an artificial basin on a flooded – but formerly terrestrial – site; therefore, few reservoirs have naturally occurring populations of native aquatic plants. The sediments of many reservoirs hold seed banks of terrestrial plants that will not germinate under flooded conditions. As a result, the sediment is often a barren benthic mud that provides ideal conditions for invasion by exotic plants. In fact, many reservoirs in the US have been taken over by aquatic weeds and plant diversity is typically very low.

Fish may naturally inhabit reservoirs, but providing fish habitat is often a byproduct of the reservoir's construction and is rarely intentional. Reservoirs in the southern US are typically stocked with a variety of plant-loving fish, including largemouth bass and bluegill sunfish. As shown earlier, aquatic plants thus play a critical role in the growth of these fish by hosting prey such as insects, crustaceans and invertebrates and by providing cover that allows fish to hide from predators. However, dense monotypic beds of aquatic weeds can restrict the benefits associated with a vegetated habitat by reducing fish foraging ability. This results in a fish population with high numbers of small individuals that fail to grow large, a condition sometimes referred to as a "stunted population." Such populations consist of many individuals feeding in dense habitats which provide better forage resources for smaller individuals, but which restrict foraging opportunities for larger fishes. A plant density that results in coverage of 20 to 60% of the surface area within the littoral zone generally provides the best fish habitat and recreational opportunities in reservoirs.

Natural lakes

Many natural lakes form as a result of natural events such as flowing water, earthquakes and animal activities like dam building, but most natural lakes in the northern US are the result of glacial disturbance. These systems were formed many years ago (most recently ten thousand years ago) and are often vegetated by diverse collections of native and endemic aquatic plants. Therefore, management of natural lakes differs significantly from methods used in reservoirs which are usually dominated by monocultures of invasive species.

Natural lakes are diverse in both aquatic plants and fish. Like reservoirs, most of the fish in natural lakes require a structural habitat at some point in their lives. In fact, many are plant-loving fish that choose to spend much of their life feeding and growing in vegetated habitats. The diversity of native and endemic aquatic plants furnishes the littoral zone with a wide variety of structures that differ in size and plant composition, a condition referred to as habitat heterogeneity. This diverse habitat is home to a number of fishes adapted to this environment, including largemouth bass, bluegill, crappie, northern pike, muskie, young perch and walleye.



Summary

Most freshwater fish rely on aquatic plants at some point during their lives and prefer specific habitats based on their growth stage. Young fish use aquatic vegetation as a food source – both by directly consuming plants (in most cases incidentally) and by foraging for the microfauna associated with the plants – and as cover to hide from predators. Mature fish move to more open waters to increase foraging success and consume other fish to supplement their diets. Nesting, growth and foraging success of plant-loving fish are influenced by plant composition and density. While many fish require some aquatic vegetation for optimal growth, excessive amounts of aquatic vegetation can negatively impact growth by reducing foraging success. Also, different fish prefer different types of habitats and will move to a new area if foraging conditions in their preferred location decline due to excessive growth of aquatic weeds.

An "optimal", one-size-fits-all fish habitat is impossible to describe, which leads to confusion and often erroneous conclusions. For example, a crappie fisherman has a different idea of a perfect habitat than does a bass fisherman. The parameters of an ideal habitat change based on the size and species of fish, the type of lake, structures present in the lake and numerous other factors. However, the "optimal" habitat that provides a beneficial environment for most animal populations is one that contains a large diversity of native plants.

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Page 9: Energy cycle; Horne and Goldman 1994
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Page 11: Largemouth bass; Dean Jackson, professional fisherman
Page 12: Black crappie; Lawrence Page, Florida Museum of Natural History
Page 13 upper: Common carp; Richard A Bejarano, Florida Museum of Natural History
Page 13 lower: Northern pike; Robin West, US FWS
Page 14: Yellow perch; Duane Raver, US FWS
Page 17: Low vs. high heterogeneity; Eric Dibble, Mississippi State University

Chapter 3: Impact of Invasive Aquatic Plants on Waterfowl

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Introduction

Studies that evaluate the relationship between waterfowl and aquatic plants (native or nonnative) usually focus on the food habits and feeding ecology of waterfowl. Therefore, the purpose of this chapter is to describe the dynamics of waterfowl feeding in relation to aquatic plants. The habitats used by waterfowl for breeding, wintering and foraging are diverse and change based on the annual life cycle of the waterfowl and seasonal conditions of the habitat. For example, waterfowl require large amounts of protein during migration, nesting and molting and they fulfill this requirement by consuming aquatic invertebrates. A strong relationship exists between high numbers of aquatic invertebrates and diverse aquatic plant communities, so diverse plant communities play an important role in waterfowl health by hosting the invertebrates needed to subsidize waterfowl migration, nesting and molting. After all, waterfowl native to the US have evolved alongside diverse plant communities that are likewise native to the US and utilize these plants to meet their energy needs. Metabolic energy demands of waterfowl are high during the winter months, so waterfowl need foods that are high in carbohydrates such as plant seeds, tubers and rhizomes during winter. Many ducks will sometimes abandon aquatic plant foraging while on their wintering grounds and feed instead on high-energy agricultural crops such as wheat, corn, rice and soybeans.

The nutritional requirements of waterfowl have historically been met in shallow lakes and wetlands where diverse aquatic plant growth is abundant. It is therefore important to understand the interactions between waterfowl and aquatic plants in order to provide quality habitat throughout migration corridors. The abundance and availability of quality habitat with adequate food cover and water is the most important ecological component affecting waterfowl populations. In order to support waterfowl health, breeding and survival, the maintenance of quality habitats is crucial so that waterfowl have access to foods they prefer instead of having to feed on what is available.

The preferred food habitats and feeding ecology of waterfowl differ based on the group of waterfowl (i.e., dabbling ducks, diving ducks, or geese and swans). For example, dabbling ducks (also called puddle ducks) vary greatly in size and "tip up" during feeding. Their feeding is constrained by how far their necks can reach into the water column (12 to 18") and depth of the water, so dabbling ducks prefer habitats with shallow water and/or moist soil. Diving ducks typically dive (as their name implies) to feed on benthic organisms such as clams and snails or to forage in sediments for tubers and rhizomes of aquatic plants. Geese and swans are the largest of the waterfowl and typically consume more plant material than dabbling ducks and divers; however, as the availability of natural habitats is diminished, geese and swans have shifted from primarily feeding in wetlands to extensive grazing in agricultural areas.

Dabbling (puddle) ducks

Dabbling waterfowl include such species as the mallard (*Anas platyrhynchos*), blue-winged teal (*Anas discors*), green-winged teal (*Anas crecca*), wood duck (*Aix sponsa*), gadwall (*Anas strepera*), northern pintail (*Anas acuta*), northern shoveler (*Anas clypeata*) and American widgeon (*Anas americana*). Most dabbling species are non-selective in their feeding habits and feed primarily on aquatic or moist-soil vegetation that is abundant in a given location. Dabblers will alter their diets as necessary to take advantage of food resources that are available and abundant. Food selection by dabbling ducks often changes based on the season and energy requirements of the waterfowl. Protein is important during spring and summer to ensure breeding success, so invertebrates are critical components in the diet of dabbling waterfowl during these seasons. In late fall and winter, dabblers consume plant material that is high in carbohydrates so they can maintain energy levels and generate body heat throughout the winter months. Dabbling waterfowl utilize submersed plant species as carbohydrate sources to fulfill their energetic demand. Most consume seeds as their primary food source, but some species (mainly widgeon and gadwall) use vegetative parts of plants as well. Also, the specialized bill structure of the shoveler, or spoonbill, allows for sifting and consumption of planktonic algae, which are high in carbohydrates.

Submersed plant communities play important roles in the annual life cycle of dabbling waterfowl. These communities are a direct source of food and also serve as an environment that supports a diversity of aquatic invertebrates. The primary submersed aquatic plants consumed by dabblers are the native pondweeds (*Potamogeton* spp. and *Stuckenia* spp.). The fruits, seeds, starchy rhizomes and winter buds of these species are favored carbohydrate sources for dabbling waterfowl, and sago pondweed (*Stuckenia pectinata*) is reportedly one of the food plants most sought after by these waterfowl. Sago pondweed is likely the single most important waterfowl food plant in the US and often accounts for a significant proportion of the food consumed by fall staging waterfowl, pre-molting waterfowl, flightless molting waterfowl and ducklings.

Diverse plant communities with a wide variety of submersed, floating and emergent plants have more architectural structure and habitat for invertebrates, which results in a greater selection of food sources for dabbling waterfowl. Water bodies that are infested with nonnative species such as hydrilla (Chapter 15.1), Eurasian watermilfoil (Chapter 15.2) and curlyleaf pondweed (Chapter 15.3) lack the habitat complexity required to support diverse invertebrate communities and are not preferred feeding areas for dabbling waterfowl. These nonnative species form dense canopies at the surface of the water, reduce native plant diversity and reduce the carrying capacity of the ecosystem. Also, if large portions of the littoral zones of several water bodies within an area are infested with nonnative plants, waterfowl may be required to continually move in search of adequate forage and resting areas. This constant movement results in poor body condition since high expenditures of energy impact wintering, migration and/or breeding fitness. Birds that are in poor body condition when returning to northern breeding grounds may have reduced nesting success or may not nest at all. Some dabbling ducks such as the wood duck nest in tree cavities, whereas other dabbling waterfowl nest in upland prairie habitat, so nonnative emergent plant species such as purple loosestrife (Chapter 15.12) and phragmites (Chapter 15.11) would not impact nest site selection for dabblers as it does for some diving species of waterfowl. However, if shallow wetlands and moist-soil areas become infested with invasive emergent weeds, the quality of food and refuge habitat for ducklings and molting waterfowl could be diminished during summer months and could ultimately reduce survival. For example, ducklings and smaller species of dabbling waterfowl such as blue and green-winged teal feed in moist soil and in areas where water depths do not exceed 8 to 12 inches. As a result, dense infestations or monotypic stands of invasive weeds can limit foraging efficiency and food quality for these ducks.

Diving ducks

Common diving ducks in North America include canvasback (*Aythya valisineria*), redhead (*Aythya americana*), lesser scaup (*Aythya affinis*), greater scaup (*Aythya marila*), ring-necked duck (*Aythya collaris*), bufflehead (*Bucephala albeola*) and common goldeneye (*Bucephala clangula*). Sea ducks and mergansers will not be discussed because sea ducks are rarely observed on inland waters and mergansers mainly consume fish.

The diet structure of diving ducks is similar to that of dabbling waterfowl because diving ducks also rely on aquatic plants, their diet alternates with the annual life cycle of the birds and food selection is influenced by gender. Female diving ducks typically consume more invertebrates during nesting, incubation and brood rearing to maintain the protein and fat stores that result in good body condition. In contrast, male diving ducks (particularly older juveniles and adults) tend to consume more plant material. Canvasback ducks feed primarily on seeds and tubers of pondweeds and the native submersed plant vallisneria (*Vallisneria americana*), from which the bird takes part of its Latin name. Vallisneria is widely distributed and is considered the most important food source for canvasback ducks. Displacement of native vallisneria by invasive plants such as Eurasian watermilfoil or hydrilla will impact canvasback foraging behavior and can lead to annual fluctuations in canvasback populations. Canvasback numbers could decline or expand depending on the quality and abundance of vallisneria-dominated communities, which is linked to competition with invasive plants. Pondweeds are also very important food sources for redhead and ring-necked ducks, but these two species forage in shallow-water areas more frequently than other types of diving waterfowl and therefore consume a diversity of plant material. Ring-necked ducks feed heavily on wild rice (*Zizania palustris*), coontail (*Ceratophyllum demersum*), sedges (*Carex* spp.), rushes (*Scirpus* spp.) and the seeds and tender submersed shoots of the floating plant watershield (*Brasenia schreberi*). However, divers such as ring-necks are highly adaptive foragers and will reportedly feed on hydrilla tubers if hydrilla populations are abundant on their wintering grounds, particularly in large inland water bodies in Florida. The two species of scaup generally consume more invertebrates than plant matter, but plants do become important to scaup during fall and winter. With the exception of the ring-necked duck, all diving waterfowl will readily switch to feeding on mussels and clams in southern wintering grounds if plant material is limited.

Nonnative submersed weeds such as hydrilla, Eurasian watermilfoil and curlyleaf pondweed would also have an impact on feeding activities of diving waterfowl. Since native pondweeds comprise a considerable portion of the food consumed by diving waterfowl, any reduction in the abundance or richness of these native plant species would have an adverse impact on waterfowl in that area. Diving waterfowl will reportedly consume the seeds of Eurasian watermilfoil and tubers of hydrilla; however, these observations were reported in areas heavily infested with these weeds and waterfowl were forced to forage on dense stands of these exotic plants, as their preferred native species were unavailable. It should also be noted that some propagules such as seeds can pass through the digestive tract of waterfowl and still be viable. Even if waterfowl utilize nonnative plants as food sources, this may result in long-distance dispersal and spread of aquatic weeds to other areas of the country. Water bodies should be managed to promote the growth of a diversity of native aquatic plants because these are most utilized by diving waterfowl and they provide habitat for greater numbers and species of invertebrates.

Diving species of waterfowl also require emergent aquatic plants for nesting habitat. Canvasbacks and redheads nest almost exclusively above the water in specific types of vegetation. Hardstem bulrush (*Scirpus acutus*), cattails (*Typha* spp.), bur-reed (*Sparganium* spp.) and sedges that extend 1 to 3 feet above the water surface are preferred habitat for nesting. These plant species generally have more succulent and flexible stems that waterfowl can manipulate for nest construction. Nonnative plant species such as purple loosestrife and phragmites have hardened, woody stems that do not support waterfowl nesting. Purple loosestrife and phragmites will also outcompete native plants preferred for nesting, which further reduces breeding habitat that is becoming scarce due to pressure from human development and agricultural practices.

Geese and swans

Geese (Canada, snow and white-fronted) are primarily vegetarian and have shifted their feeding ecology toward agricultural grains and/or green-fields, including golf courses and parks. For example, corn and wheat have provided the majority of food for migrating and wintering Canada geese in recent decades and rice is frequently consumed by geese in the southern US. When agricultural grains become scarce in late winter, geese will feed on the green tissue of native moist-soil plants such as millets (*Echinochloa* spp.), smartweeds (*Polygonum* spp.), cut-grasses (*Leersia* spp.) and spikerushes (*Eleocharis* spp.). This switch in food sources also corresponds to times when crude protein is needed for migration and nesting. Swans are also primarily vegetarian but feed on aquatic plants more than do geese. The diets of swans are based primarily on wigeongrass (*Ruppia maritima*), pondweeds and vallisneria during the winter months, but swans will forage in agricultural fields, golf courses or urban lawns when populations of aquatic plants are depleted.

Summary

Dabbling ducks, diving ducks, geese and swans are generalists and will consume the food sources available in a given area. Waterfowl prefer to forage and rest in shallow-water habitats that support diverse communities of submersed plants, including nonnative species. However, waterfowl usually prefer native species of aquatic and moist-soil plants to nonnative, invasive vegetation. Dabbling waterfowl prefer seeds of smartweed, millet, pondweeds, sedges and rushes, as well as invertebrates that typically thrive in association with these plants. Although waterfowl will utilize nonnative plants, these species are generally not preferred and are consumed only because they are locally abundant. Diving ducks such as canvasbacks and redheads rely heavily on pondweeds and vallisneria, but nonnative aquatic weeds such as Eurasian watermilfoil, hydrilla and curlyleaf pondweed can outcompete and reduce the presence of these valuable and desirable native plants. Furthermore, dense infestations of nonnative emergent species such as purple loosestrife and phragmites reduce the already-dwindling nesting habitat for many waterfowl species. North American waterfowl have evolved and thrive in habitats that support a variety of diverse native aquatic plants and management should focus on removing monotypic stands of nonnative plants to promote native plant growth.

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Page 23: Snow geese; Lee Karney, US FWS

Chapter 4: Impact of Invasive Aquatic Plants on Aquatic Birds

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Introduction

Birds that live at least part of their lives in or around water are referred to as aquatic birds and/or water birds. Each species has specific requirements that must be met in order to reproduce, survive, grow and reproduce again. It can be challenging to make broad statements that apply to all aquatic birds, but they are often grouped into subclasses based on habitat preference, which allows generalizations to be made about birds with similar requirements. Waterfowl are discussed in Chapter 3, but other groups of aquatic birds that use similar habitats include marsh birds, shorebirds and wading birds.

Marsh birds live in or around marshes (treeless wet tracks of grass, sedges, cattails and other herbaceous wetland plants) and swamps (wet, soft, low, water-saturated land that is dominated by trees and shrubs). This is a broad category that includes many unrelated species of birds, all of which prefer to nest and/or live in marshy, swampy areas. Marsh birds include herons, storks, ibises, flamingoes, cranes, limpkins and rails.

Shorebirds inhabit open areas of beaches, grasslands, wetlands and tundra. These birds, which include plovers, oystercatchers, avocets, stilts and sandpipers, are often dully colored and have long bills, legs and toes.

Wading birds generally do not swim or dive for prey, but instead wade in shallow water to forage for food that is not available on shore. Wading birds include herons, egrets, spoonbills, ibises, cranes, stilts, avocets, curlews and godwits. These birds generally have long legs, long bills and short tails, which allows them to strike and/or probe under the water for fish, frogs, aquatic insects, crustaceans and other aquatic fauna.

It is easy to see that some birds can fall into several of these general groups, so care should be taken when interpreting statements applied to birds in these groups. These subclasses group birds based on habitat preference, but birds are complex, adaptable animals. Thus, regardless of habitat, it may be possible to observe many different aquatic bird species if adequate food sources are available. The purpose of this chapter is to describe how aquatic birds are related to lake morphology, water chemistry and aquatic plants in lake systems and how the presence of large monocultures of exotic invasive plants such as hydrilla (Chapter 15.1) and phragmites (Chapter 15.11) may impact aquatic bird communities.

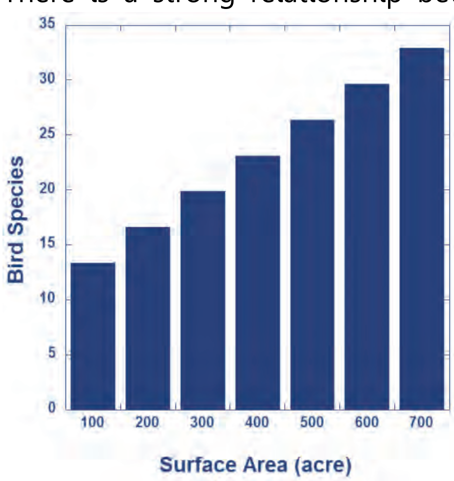
Lakes and aquatic bird communities

Birds are an integral part of all lake systems, but their role in the ecology of lakes has frequently been overlooked. This is surprising, since aquatic birds are often the first wildlife that is seen when visiting a lake and the vast majority of people who visit lakes enjoy their beauty and grace. However, the majority of earlier research and management conducted on lake systems involved nutrient enrichment problems and aquatic plant management. The focus of this early research was primarily to provide potable water, flood control, navigation, recreational boating, swimming and fishing and consideration was seldom given to aquatic bird communities that utilized these lakes. As a result, little information is available regarding how these different lake management activities affect aquatic bird communities.

This situation began to change rapidly in the 1980s when many ornithologists (scientists studying birds) and limnologists (scientists studying freshwater systems) became increasingly conscious of the importance of birds to aquatic systems. These researchers have worked together to identify many significant relationships between lake limnology and aquatic bird populations. This research can be used to predict the impact of habitat changes resulting from invasion by aquatic weeds and from lake management programs on aquatic bird communities.

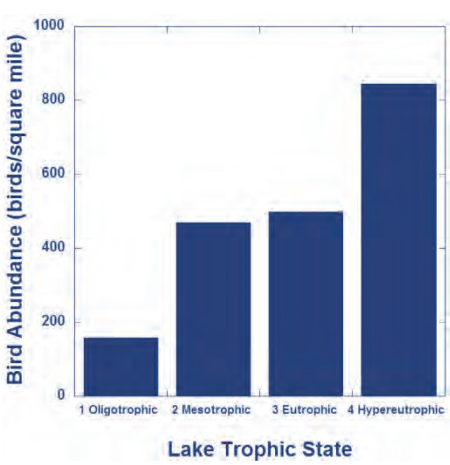
Lake area and aquatic bird species richness

There is a strong relationship between bird species richness (the number of bird species in an aquatic community) and the surface area of the lake they inhabit. Many studies have shown that plant and animal species richness increases as habitat area increases. Most researchers and lake managers agree that larger areas are more likely to include diverse habitats that allow more species niches. Based on this theory, the invasion of a lake system by an exotic species and the resulting monoculture of a single aquatic plant would decrease other environmental niches and would decrease the number of species of aquatic plants and ultimately aquatic birds using that lake system. However, there are few studies that document this type of impact of aquatic weeds on bird populations.



Lake trophic state and aquatic bird abundance

Lake trophic state is the degree of biological productivity of a water body. Biological productivity generally describes the amount of algae, aquatic plants, fish and wildlife a water body can produce. The level of trophic state is usually set by the background nutrient concentrations of the geology in which the lake lies, because nutrients (primarily phosphorus and nitrogen) are the most common factors limiting growth of algae and plants that form the base of the biological food



chain (Chapter 1). It is therefore not surprising that lakes with higher trophic states generally support more aquatic birds, since these lakes usually have an abundance of plants and animals that can be used for food and shelter by aquatic birds. Some question whether aquatic birds show up because a lake is productive or whether the lake becomes productive because birds bring nutrients to the system. There have been instances where large flocks of birds such as geese feed on terrestrial agricultural grains and then roost on a lake, ultimately causing elevated nutrient concentrations in a lake. However, most current research suggests that the majority of aquatic bird communities extract their nutrients from the lake and function more as nutrient recyclers than as nutrient contributors.

Most lake management efforts are directed toward the manipulation of lake trophic state, with most resources focused on reducing nutrients caused by anthropogenic activities. However, management agencies in some areas will actually add fertilizer (nutrients) in an attempt to increase productivity of plants, algae and fish, which increases angling activities. In either case, changes to the trophic state of a lake system will have a corresponding impact on the aquatic birds that utilize the lake. If aquatic birds are an important component of an individual lake, this relationship needs to be considered before nutrient manipulations occur.

Aquatic plants and aquatic bird communities

Aquatic birds rely on aquatic plants to meet a large variety of needs during their life cycles. Some birds nest directly in aquatic plants, whereas others use plants as nesting material, foraging platforms, for resting and for refuge from predators. Aquatic plants are eaten by some bird species; in addition, some plants support attached invertebrates that are used as a food source by some aquatic birds. Since there are so many associations between the needs of aquatic birds and aquatic plants, it would be reasonable to expect a strong relationship between the abundance of all aquatic birds and the abundance of aquatic plants in a lake system.

However, multiple studies have found no such relationship after accounting for differences in lake trophic state. This surprising lack of relationship between total bird abundance and total abundance of aquatic plants can be explained by the fact that individual bird species require different types and quantities of aquatic plants. Research has suggested that aquatic bird species can be divided into three general groups:

1) birds that are directly related to the abundance of aquatic plants
2) birds that are negatively affected by an abundance of aquatic plants
3) birds that have no relationship to the total abundance of aquatic plants but require the presence of a particular plant type for completion of their life cycle

However, these are loose generalizations and individual species of aquatic birds can transcend these plant groupings depending on the given lake system and the bird's life requirements.

Birds that are directly related to the abundance of aquatic plants. Many waterfowl, including the coots and ring-necked ducks described in Chapter 3, use aquatic plants as a food source and thus are generally more abundant in lakes with an abundance of aquatic plants. Other aquatic birds that prefer a habitat with plentiful aquatic plants include limpkins and curlews. These species are generalized feeders that consume insects, fish, small animals, snails and other aquatic fauna that are associated with aquatic vegetation. Limpkins and curlews are often observed walking on and foraging in floating aquatic plants, waterhyacinth (Chapter 15.7), salvinia (Chapter 15.9), native waterlilies and other plants when this vegetation is present in densities sufficient to support the weight of the birds. If this type of habitat is not available, these birds will forage along sparsely vegetated shorelines and mudflats where water is shallow enough to allow wading. Birds in this group prefer lakes with an abundance of aquatic plants; however, these species will often locate and feed in more diverse habitats when their preferred environment is not available to them.

Birds that are negatively affected by an abundance of aquatic plants. Some bird species, such as snakebirds (*Anhinga anhinga*) and double-crested cormorants (*Phalacrocorax auritus*), must swim through the water to catch fish, crayfish, frogs and other aquatic fauna. Large amounts of aquatic vegetation interfere with the feeding ability of these aquatic birds; therefore, these types of birds tend to decrease in abundance when submersed weeds become abundant in a lake system. Other aquatic birds that prefer sparsely vegetated water are the threatened piping plover (*Charadrius melodus*) and the endangered interior least tern (*Sterna antillarum athalassos*). These species once fed, nested and were abundant on sandbars along the Missouri and Platte Rivers and in other similar areas in the central and northern US; however, piping plovers and interior least terns have experienced major population declines in the last 50 years. Dredging and damming of rivers has destroyed most of the sandbar habitat preferred by these species and flood control projects have reduced scouring and re-forming of new sandbars. In addition, old sandbars have become densely vegetated, further reducing the nesting and feeding grounds required by these aquatic birds. This is particularly problematic in the Midwest, where phragmites and purple loosestrife (Chapter 15.12) have invaded most sandbars formerly inhabited by piping plovers and interior least terns.

Some aquatic birds are only affected by certain types of aquatic weeds. For example, eagles and ospreys soar over open water in search of fish swimming near the surface of the lake, so submersed aquatic weeds rarely hinder feeding by these species. In fact, since submersed plants reduce wind and wave action and improve water clarity, the presence of these aquatic plants may actually increase the feeding efficiency of sight feeders such as eagles and ospreys. However, dense populations of floating plants and floating-leaved plants (e.g., waterhyacinth, salvinia, waterlilies, etc.) may negatively impact the foraging success of sight-feeding aquatic birds because fish are hidden beneath the vegetation. Sight feeders may be forced to abandon lakes that are heavily vegetated with these types of plants and seek out new habitats with open water that provide an unobstructed view of their prey.

Birds that have no relationship to the total abundance of aquatic plants but require the presence of a particular plant type for completion of their life cycle. Some aquatic bird species – including the secretive American bittern (*Botaurus lentiginosus*) and least bittern (*Ixobrychus exilis*) – require tall, emergent vegetation like cattails and bulrush for concealment from predators regardless of the total amount of aquatic vegetation present in the lake. Both species of bittern "freeze", with neck

outstretched and bill pointed skyward, when danger threatens and sway in imitation of wind-blown emergent vegetation such as cattails. Even nestling least bitterns, still covered with down, adopt this posture when threatened. Invasion by exotic species of aquatic plants would probably not impact this type of bird species unless the exotic species reduces the abundance of the required aquatic plant.

Many wading birds also fall into this group and do well in lakes regardless of the amount of aquatic plants, but one factor that may limit the success of these wading birds is the availability of water shallow enough for them to forage for food. Wading birds that inhabit lakes regardless of the abundance of aquatic plants include great blue heron (*Ardea herodias*), great egret (*Ardea alba*), snowy egret (*Egretta thula*), little blue heron (*Egretta caerulea*) and tricolored heron (*Egretta tricolor*). Larger wading birds can forage in water of greater depths, which increases the area available for foraging. Therefore, the great blue heron has an advantage over the smaller little blue heron in open water. However, larger wading birds may become tangled in vegetation when an invasive exotic species covers a lake; on the other hand, many of the smaller wading birds can actually wade on top of dense plant growth, which vastly increases their foraging area.

Summary

Aquatic birds come in an almost infinite number of sizes and shapes and require many different resources to complete their life cycles. A number of generalizations can be made regarding groups of similar bird types, but it is important to remember that all species are somewhat different. Also, individual species are adaptable and often able to use available resources even if those resources are not preferred. Encroaching invasive exotic plants can increase, decrease or have little impact on a particular aquatic bird, which makes it difficult to predict the impact of aquatic plants on a given species. This dilemma becomes even more challenging when you consider that birds fly and can easily travel from lake to lake to find the habitat that best suits their needs, even though the distance seems prohibitive.

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Page 29: Least bittern; Mark Hoyer, University of Florida Fisheries and Aquatic Sciences

Chapter 5: Aquatic Plants, Mosquitoes and Public Health

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Introduction

Approximately 200 species of aquatic plants are classified as weeds in North America and nearly 50, or 25%, are considered to be of major importance. Aquatic plants become weedy or invasive when they exhibit rapid growth and produce dense monocultures that displace more desirable native plants, reduce biodiversity, interfere with flood control, impede navigation and create breeding sites for disease-vectoring mosquitoes.

Mosquitoes are insects that belong to the family Culicidae in the order Diptera, or true flies. They are similar in appearance to other flies except they have fragile bodies and their immature stages (eggs, larvae and pupae) develop entirely in aquatic environments. These insects are serious pests that have plagued civilizations throughout human history. In addition to their annoying and often painful bites, they transmit some of the world's most devastating diseases – dengue, encephalitis, yellow fever, dog heartworm and the dreaded malaria. According to a recent report from the University of Florida, more than 500 million new cases of malaria are reported worldwide each year, resulting in about 1 million deaths. Most of the deaths that are caused by malaria are in children under 10 years of age. The importance of mosquitoes from a nuisance and public health perspective cannot be overstated.

Malaria

Malaria was endemic in the US until around 1950 when window screens, air conditioning and mosquito control efforts essentially eliminated malaria in this country. Malaria is caused by four species of a protozoan parasite in the genus *Plasmodium*. This parasite, which is transmitted by a mosquito bite, destroys red blood cells and causes fever, chills, sweating and headaches in infected humans. If not treated, individuals that have become infected with malaria may go into shock, experience kidney failure and eventually slip into a coma and die. The disease is transmitted by several species of *Anopheles* mosquitoes, which are permanent water mosquitoes (see below). These species are widespread and are most abundant from early spring (April) to early fall (September). Until recently, reported cases of malaria in the US were from travelers and returning military personnel who contracted the disease outside the country. However, cases of malaria occur periodically in the US when indigenous *Anopheles* mosquitoes transmit the disease from an infected human who traveled abroad to an uninfected human.

Dengue fever

Dengue is a viral disease, often referred to as "breakbone fever". Symptoms of this mosquito-transmitted disease include headaches, high fever, rash, backache and severe pain in the joints. The excruciating joint pain gives rise to the common name. Disease symptoms usually occur about a week after a susceptible human has been bitten by an infected mosquito and rarely result in death. However, because four strains of dengue virus are recognized, exposure of a previously infected individual to a different strain of dengue virus may result in a more severe case of dengue known as dengue hemorrhagic fever (DHF). There has been an increase in the incidence of DHF in the Western Hemisphere during the last 20 years, with outbreaks occurring in the Caribbean region. Ideal conditions for dengue transmission are present in the southern US. The virus often is "imported" by people entering the country from the tropics. Also, the potential mosquito vectors (yellow fever mosquito, *Aedes aegypti*, and the Asian tiger mosquito, *Aedes albopictus*) are commonly found in close association with humans, breeding in natural and artificial water-holding containers near homes and businesses.

Encephalitis

Encephalitis means inflammation of the brain and is a disease of the central nervous system. Although there are several possible causes for encephalitis, one of the most important involves mosquitoes. Mosquito-transmitted viruses are commonly referred to as arthropod-borne or arboviruses. There are six major types of arboviral encephalitis in the US: California encephalitis (CE), Eastern equine encephalitis (EEE), St. Louis encephalitis (SLE), Venezuelan equine encephalitis (VEE), Western equine encephalitis (WEE) and West Nile virus. These viruses are normally diseases of birds or small mammals and each is caused by a different virus or virus complex. Humans and horses are considered "dead end" hosts for these viruses as there is little chance of subsequent disease transmission back to mosquitoes. However, human and horse cases of arboviral encephalitis range from mild to severe, with permanent damage to the central nervous system or even death. Mosquito genera involved in the transmission of arboviruses include *Aedes*, *Anopheles*, *Culex*, *Culiseta*, *Ochlerotatus*, *Coquillettidia* and *Psorophora*.

Yellow fever

Like dengue fever, the yellow fever virus is transmitted primarily in urban areas by the container- breeding mosquitoes *Aedes aegypti* and *Aedes albopictus*. But unlike dengue, the effects on humans are more severe. During outbreaks, the human fatality rate often exceeds 50% of the affected population. Fortunately, the yellow fever virus is restricted to parts of Africa and South America. The likelihood of the yellow fever virus causing an epidemic in the US is extremely low for several reasons. First of all, yellow fever is a quarantinable disease; the Centers for Disease Control and Prevention in Atlanta continually monitor disease outbreaks in the Western hemisphere. Secondly, travelers planning to visit parts of Africa and South America where the virus is endemic are vaccinated to prevent infection. Finally, humans moving to virus-free areas from locations where the virus occurs naturally are required to be vaccinated to prevent transmission.

Heartworms

The filarial nematode (microscopic worm) *Dirofilaria immitis* is responsible for dog heartworm, a serious mosquito-transmitted disease that affects all breeds of dogs. Although the disease occurs in temperate regions of the US, it is more of a concern along the Atlantic and Gulf Coasts from Massachusetts to Texas. If left untreated, the infection rate in dogs can range from 80 to 100%. Foxes and coyotes probably serve as reservoirs for the disease. Cats and humans also can be infected but the parasite is unable to complete its development in humans. Mosquitoes in most of the common genera, including *Aedes*, *Anopheles*, *Culex*, *Ochlerotatus*, *Mansonia* and *Psorophora*, are capable of transmitting the disease. The life cycle of dog heartworm begins when an infected mosquito feeds on a dog. Juvenile worms (microfilariae) emerge from the mouthparts of the feeding mosquito and enter the dog’s skin. The worms migrate in the muscle tissue for 3 to 4 months, penetrating blood vessels and eventually making their way to the right ventricle of the dog’s heart, hence the name “dog heartworm”. The worms reach maturity in around 5 months; adult female worms measure about 1 foot in length whereas males are only 6 inches long. The life cycle is completed when the adult female produces microfilariae that circulate in the blood and are ingested by a mosquito during a blood meal. Medication for preventing dog heartworm is available from veterinarians.

The role of aquatic plants in mosquito outbreaks

The aquatic stages of most mosquitoes are not adapted to life in moving waters. They require quiet pools and protected areas where they can obtain oxygen at the water surface via a single air tube (or siphon) in the larval stage or two tubes (or horns) in the pupal stage. Aquatic weed infestations create ideal habitats for mosquito development because the extensive mats produced by many weeds reduce the rippling effect of the water surface. Some mosquito species even have a modified air tube that they insert into the roots of aquatic plants to obtain oxygen. This protects them from light oils that are applied to the water surface for mosquito control.

From a mosquito control perspective, there are two major larval habitat categories that are of concern to aquatic plant managers: standing water (permanent and temporary) and flood water (detention and retention areas). Permanent water mosquitoes (e.g., species in the genera *Anopheles*, *Culex*, *Coquillettidia* and *Mansonia*) are associated with aquatic plants in freshwater marshes, lakes, ponds, springs and swamps. Temporary water mosquitoes (e.g., species in the genera *Culiseta*, *Ochlerotatus* [=*Aedes*] and *Psorophora*) are associated with vegetation in saline or brackish ditches, borrow pits and canals and freshwater drainage ditches which alternate between wet and dry based on water use and rainfall events.

Permanent water

The amount and type of vegetation occurring in a permanent water body is a good indicator of its potential to produce mosquitoes. For example, the presence of floating mats of cattails, torpedograss, alligatorweed or para grass suggest that larvae of permanent water mosquitoes are likely to be present. Also, dense stands of aquatic plants create ideal conditions for mosquito development by restricting water flow in drainage and irrigation ditches.

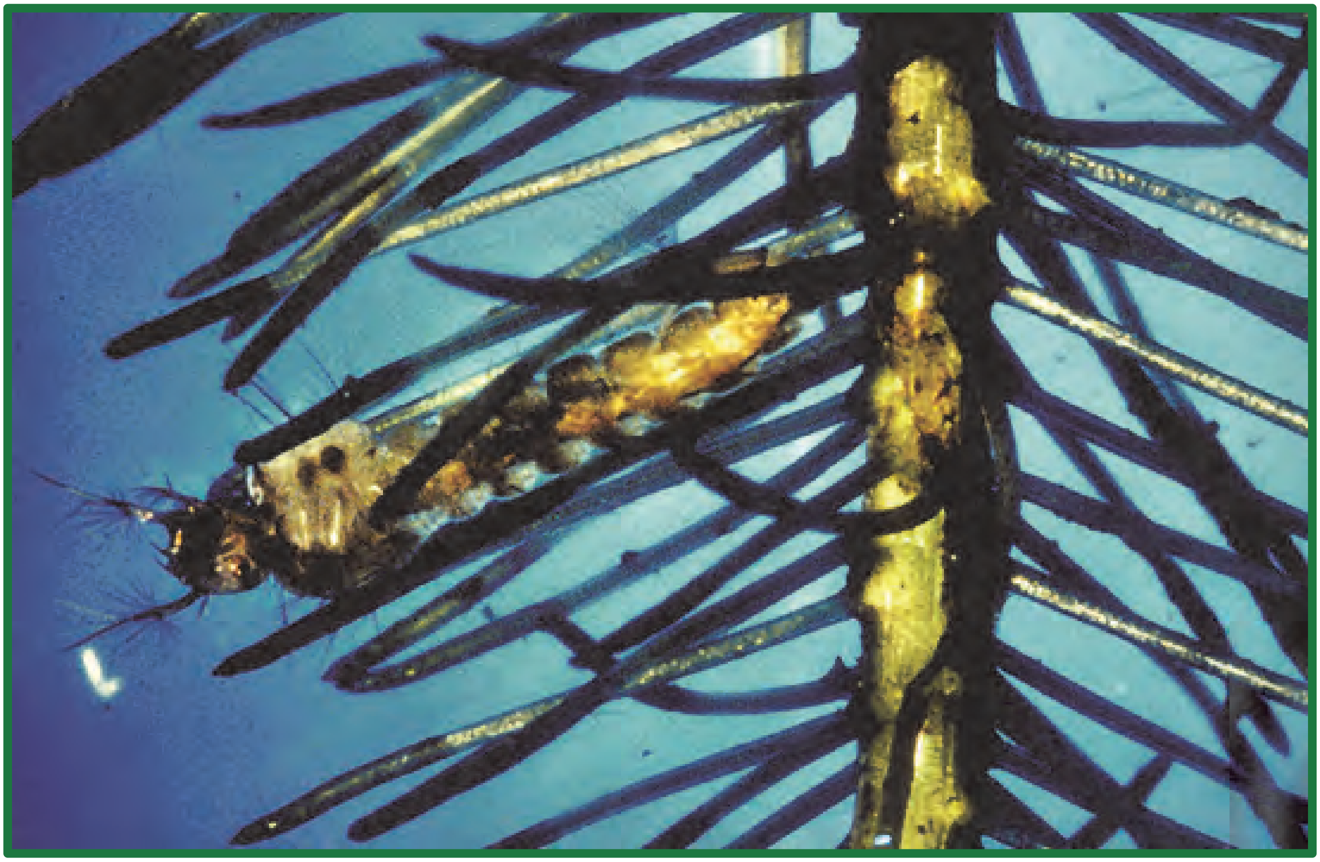
Flood water

Detention and retention systems are artificial ponds designed to capture flood water from rainstorm events and filter it before it enters natural systems. Construction of storm water detention/retention areas has increased dramatically throughout the US and they are often required by law for all new commercial and residential developments. Detention ponds differ from retention ponds by the length of time they are "wet." Detention ponds dry out only during drought conditions, whereas retention ponds are designed to dry out rapidly, usually within 72 hours. Under the right conditions, both types of flood control systems can produce aquatic vegetation that can foster mosquito outbreaks. Unless they are properly managed, detention/retention areas overgrown with aquatic vegetation can lead to serious mosquito problems. Detention ponds normally do not produce many mosquitoes unless they alternate between the wet and dry cycles that are required to produce floodwater mosquitoes.

However, if they are not properly managed, they often are invaded by floating and rooted aquatic plants. The only way to prevent a mosquito problem in residential and commercial detention/ retention areas that contain these mosquito-producing plants is to control the plants.

Mosquitoes associated with specific aquatic plants

Some species of mosquitoes are associated with certain species of aquatic plants. For instance, the permanent water mosquito species *Coquillettidia pertubans*, *Mansonia dyari* and *M. titillans* are always associated with waterlettuce (Chapter 15.8), waterhyacinth (Chapter 15.7) and cattails. The extensive fleshy root systems of these species provide an ideal substrate for *Mansonia* larvae to



attach and obtain oxygen through air tubes they insert into the plant roots. Also, the fleshy root system of cattail often harbors larvae of *Coquillettidia* mosquitoes. The roots of cattails and other plants also afford mosquito larvae some measure of protection from predators (including fish), as they are hidden from them. Other plants are good indicators of areas likely to produce floodwater mosquitoes. For example, sites with grasses, sedges and rushes often host enormous numbers of *Psorophora* mosquitoes that are vicious biters. On the other hand, the presence of extensive mats of duckweed (Chapter 15.10) or salvinia (Chapter 15.9) is indicative of low mosquito production areas. Although the root system of salvinia is highly branched, this floating aquatic plant is not a preferred host for mosquito larvae.

Summary

The association between aquatic plants and certain species of mosquitoes has evolved over millions of years. The uncontrolled growth of invasive plants often provides an undisturbed habitat that mosquitoes prefer and where they can proliferate. Mosquitoes can colonize virtually any type of water body and aquatic vegetation provides a perfect environment for mosquitoes to thrive. Management of dense surface-growing exotic and native aquatic plants in permanent and temporary water systems is critical to reduce the habitats suitable for mosquito development. After all, "…Without aquatic plants, most of our freshwater mosquito problems would not exist…" (Wilson 1981).

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Photo and illustration credits:

Mosquito life stages photos (all from University of Florida IFAS Medical Entomology Laboratory)

Page 31: *Anopheles quadrimaculatus* eggs; Roxanne Connelly

Page 32, upper: *Culex salinarius* larva; Michelle Cutwa-Francis

Page 32, lower: Mosquito pupa; James Newman

Page 33: *Culex quinquefasciatus* adult; James Newman

Page 35: Mosquito larva attached to root of waterlettuce; T. Loyless, Florida DACS

Chapter 6: Cultural and Physical Control of Aquatic Weeds

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Introduction

Methods for cultural and physical control of aquatic weeds are often viewed as strategies that can be readily employed by lake users as well as lake managers. Cultural control typically focuses on education and preventing invasive species introductions from occurring in the first place. Physical control methods are usually non-chemical, non-motorized techniques that are employed to control aquatic weeds and range from hand-pulling to water-level drawdowns, or efforts to alter water or sediment characteristics where weeds are found. As awareness of aquatic nuisance species has grown in recent years, so have efforts to incorporate cultural and physical control methods as important elements of Integrated Weed Management Programs.

Prevention

Many states have prepared official lists of invasive aquatic species and some have even passed legislation to ban their transport or introduction. However, there are often limited resources or mechanisms to enforce rules and prevention efforts are often left to individual lake associations or other volunteer groups. The first step in prevention is regular monitoring to look for new or pioneer infestations. Volunteers can be trained to participate in lake monitoring or "weed-watcher" programs to accurately identify invasive species. In many cases a step-by-step reporting protocol is provided if a new "find" is discovered.

Education is a key component of prevention. Educating lake users and the general public about the threat of invasive species is necessary to prevent new infestations and to sustain effective aquatic plant management programs. Education involves creating public awareness of the problem and familiarizing people with possible solutions. Volunteer labor and public participation are paramount to successful education efforts.

Boat ramp monitoring programs are used to inspect boats and trailers for the presence of invasive species. These are largely volunteer or summer intern positions that try to staff boat ramps during peak use periods. Inspections can either be mandatory or voluntary and usually only take a matter of minutes. Several northeastern states provide annual reports about the number of "saves", which occur when an invasive species is found on a boat or trailer and is removed before the boat is launched. The interaction with boat ramp monitors also provides an opportunity to distribute educational material and conduct surveys about boating habitats and other water bodies that were recently visited.

Boat washing stations are also used at some locations as an aggressive education and prevention measure. Boats and trailers are washed prior to entering and sometimes after leaving a lake. Most aquatic plant fragments capable of surviving out of water are easily seen and can be removed by hand. Washing stations are probably better suited to removing microscopic threats such as zebra mussel veligers, didymo or spiny water flea. Primary considerations for boat washing stations are whether space and utilities for a station are available, the cost of installation, staffing and how wash water is captured and treated. Boaters are sometimes reluctant to utilize volunteer boat washing stations or those where a fee is charged and this is another hurdle that must be overcome for wash stations to be effective.

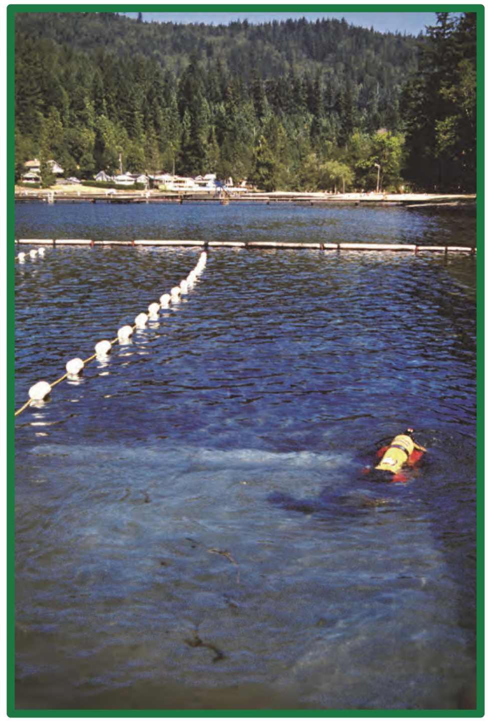
Assessment and monitoring

The accurate identification of aquatic weed infestations and their associated problems are the first steps toward developing and implementing an aquatic plant management program. Once a program is implemented, monitoring is usually warranted to evaluate the effectiveness of techniques used and to make adjustments in future years. Compliance monitoring and reporting are often a permit requirement and may focus on changes to nontarget species and water quality. The basic protocol that is recommended when initiating an aquatic plant management program is outlined in detail in Appendix D.

Physical control practices

Aeration or artificial circulation uses electric or solar powered mixers, fountains or compressed air diffuser systems to circulate and add oxygen to the water. The premise is that the addition of oxygen will reduce the amount of available phosphorus and result in less algae growth. The physical circulation or destratification (mixing) of water can also prevent noxious algal blooms from developing (Chapter 14). Benefits of aeration have been clearly documented in all types of water bodies from small, shallow ponds to large, thermally stratified lakes that are using hypolimnetic (deep water) aeration systems. Growth of some aquatic plants appears to be limited by disturbance of the physical surface of the water and may prevent canopy formation by floating plants such as duckweed or watermeal (Chapter 15.10). Recent claims that water circulators control invasive submersed species are unsubstantiated.

Benthic barriers or bottom weed barriers are used for localized control of aquatic plants through compression and by blocking sunlight. Barriers specifically manufactured for aquatic weed control are usually made from materials that are heavier than water such as PVC, fiberglass and nylon. Other fabrics used in landscaping and construction have also been tried. Barriers are usually anchored in place with a variety of fastening pins or anchoring devices. Some of the most common anchors being used are lengths of steel rebar encased in capped PVC pipes, which eliminates any sharp edges that could tear the barriers or be hazardous to swimmers. Sand bags, bricks and steel pins are also commonly used as anchors. Larger panels that are installed in water depths of greater than 4 feet usually require SCUBA divers for proper installation. Several different mechanisms have been devised to unroll the barriers in place during the installation process. Solid fabric barriers often need to be cut or vented to allow gasses to escape and to prevent billowing.



Benthic barriers are usually used to control dense, pioneer infestations of an invasive species or as a maintenance weed control strategy around boat docks and swimming areas. Large installations (greater than one acre) are often impractical due to the high cost associated with purchasing, installing and maintaining the barrier. Benthic barriers should be left in place for a minimum of 1 to 2 months to ensure that target plants are controlled, but barriers must be regularly removed and cleaned of silt; otherwise plants may begin to root on top of or through the barriers. Removal, cleaning and re-deployment is usually required every 1 to 3 years depending on the rate of silt accumulation. Some lakes with volunteer divers have attached barriers to lightweight frames that facilitate rapid deployment and retrieval. Barriers non-selectively control aquatic vegetation and may impact fish and other benthic organisms, which is another reason they are usually used for small localized areas. Many states require permits for the use of benthic barriers.

Drawdown or the lowering of the water level can be used to effectively control a number of invasive submersed species. This technique is used mostly in the northern US to expose targeted plants to freezing and drying conditions. Water is either gravity drained using a low-level gate valve or a removable flashboard system on a dam. Siphoning or pumping can also be performed in lakes with insufficient outlet structures. A principal attraction of drawdown is that it is typically an inexpensive weed control strategy for lakes with a suitable outlet structure. Annual drawdown programs can result in sediment compaction and changes in substrate composition. Drawdowns are also utilized to provide protection from ice damage to docks and other shoreline structures and to allow for shoreline clean-up and repairs by lake residents.

Plants that are usually controlled by drawdowns include many submersed species that reproduce primarily through vegetative means such as root structures and vegetative fragmentation. Some invasive submersed species most commonly targeted by drawdown include Eurasian watermilfoil (Chapter 15.2), variable watermilfoil, fanwort (Chapter 15.5), egeria or Brazilian elodea (Chapter 15.4) and coontail.

Waterlily species can also be effectively controlled, provided sediments can be sufficiently dewatered to allow for the freezing and drying conditions required to control this species. Seeds and other non-vegetative propagules such as turions or winter buds are not controlled by drawdown; in fact, species that reproduce by these means may actually increase following drawdown programs. Many species of pondweed (*Potamogeton* spp.) have increased following drawdown programs and highly opportunistic species like hydrilla (Chapter 15.1) may expand rapidly following drawdown.

A general rule of thumb is to maintain drawdown conditions for 6 to 8 weeks to ensure sufficient exposure to freezing and drying conditions. Excessive snow cover or precipitation can limit the effectiveness of this technique. Drawdowns are usually timed to begin during the fall months to avoid stranding amphibians, molluscs and other benthic organisms with limited mobility. Care must also be taken to leave enough water to support fish populations and avoid impacts during key spawning periods. Drawdowns can have negative impacts on adjacent wells and wetlands as well, so it is also important to know the downstream channel configuration, capacity and flow requirements. When properly utilized, drawdowns can be a low-cost or no-cost strategy to incorporate into an integrated management program. Many states require permits for drawdown programs.

Hand pulling is one of the simplest and most widely used methods to control aquatic weed growth and can be performed by wading or from a small boat in shallow water. Snorkeling equipment or SCUBA divers are usually used in water greater than 4 to 5 feet deep and for more intensive hand pulling programs. This can be a highly selective technique, provided the target species can be easily identified. Hand pulling is usually used as a component of invasive species management programs to target new infestations with low plant density (generally less than 500 stems per acre). Hand pulling can be used to remove more dense plant growth over small areas, but benthic barriers or suction harvesting may be more effective approaches in these situations. Hand pulling is often an important follow-up strategy to a herbicide treatment program to extend the duration of plant control.

When hand pulling a plant like Eurasian watermilfoil, the roots should be carefully dislodged from the bottom substrate so that the entire plant can be collected and removed to prevent vegetative regrowth. Once the bottom substrate is disturbed, suspended sediment often greatly reduces visibility, which results in the need to make multiple passes over the same area. In larger hand pulling programs that use multiple divers, it is often advantageous to have people in boats that can collect dive bags full of weeds and can try to capture escaping plant fragments using pool skimmers.

Waterchestnut (Chapter 15.6) is a noxious invasive species that has been effectively managed in several locations by hand pulling programs. This floating-leaved plant is easily identified and is a true annual plant that usually drops its seeds in late summer. Hand pulling efforts are usually performed for several weeks during the summer months before seed drop occurs. Several successful volunteer waterchestnut hand pulling programs have been organized and implemented in the Northeast.

Hand rakes of varying sizes and configurations are being manufactured and sold for aquatic weed control. Many of these hand rakes are lightweight aluminum, with rope tethers that are designed to be thrown out into a swim area and dragged back onto shore. Some are designed to cut the weeds instead of raking them back to shore. While these may be cost-effective strategies to manage individual swim areas, there is a risk that these rakes will make the problem worse by creating weed fragments that can escape and infest other portions of the lake.

Nutrient inactivation involves the application of aluminum or iron salts or calcium compounds (lime) to remove phosphorus from the water column and to inactivate phosphorus in the sediment. Aluminum sulfate (alum) is most commonly used. Removing and inactivating phosphorus can effectively discourage algal blooms from developing, but the growth of most rooted vascular plants is usually limited by nitrogen and there are no compounds readily available that bind with nitrogen in the sediment. Injecting sediments with alum and lime has been attempted, but suppression of vascular plant growth was not significant. Nutrient inactivation remains best suited for water quality improvement and algal control (Chapter 13). In fact, reducing water column nutrients and algae may encourage even more dense infestations of nuisance rooted plants due to improved water clarity and light penetration, which may allow weeds to grow in deeper areas.

Shading through the use of EPA-registered dyes or surface covers attempts to limit light penetration and restrict the depth at which rooted plants can grow. Dyes are usually considered non-toxic solutions that give the water a blue or black color. The use of dyes is often limited to smaller golf courses or ornamental ponds because they make the water appear artificial. Dyes have little use in larger water bodies; in addition, if the pond or lake has a flowing outlet, multiple treatments may be required. Surface covers made from various fabrics or plastic materials can be used to prevent light penetration and control rooted plant growth. This approach is generally not used in recreational ponds and lakes since they would impair access to or use of the lake. Recent studies have shown that this can be an effective means of controlling plants that do not produce seeds or other vegetative reproductive propagules, but its application is usually limited to small, highly controlled areas.

Weed rollers use a roller on the lake bottom that is powered by an electric motor and travels forward and reverse in up to a 270-degree arc around a pivot point. Rollers can be up to 30 feet long and are typically installed at the end of a dock. Plants initially become wrapped around the roller and are dislodged from the sediment; the constant motion of the rollers then disrupts and compresses the bottom sediments, which prevents plants from becoming reestablished. Because the rollers travel along a pivot point, they reportedly can be used in several different substrate types. Weed rollers are only practical for managing small areas. They may disrupt fish spawning or other benthic organisms, but these impacts would likely be minimal or highly localized. Many states require permits for the use of weed rollers.

Summary

There are a number of cultural or physical methods that can be employed by lake associations or individual lakefront owners to control aquatic weeds, but the most important function of stakeholders is to develop a prevention plan. The vast majority of new weed infestations are found near boat ramps, so these areas should be surveyed on a regular basis. Residents that regularly spend time on the lake should obtain plant identification materials from state agencies or other information sources so that exotic plants can be accurately identified and targeted for treatment. Management plans should be developed for rapid response; in other words, plans should be developed proactively and stakeholders shouldn't wait for an invasive species to appear before creating a plan. Prevention and rapid response should be top priorities among lake associations because these are the most cost-effective and ecologically sound means of protecting aquatic resources from invasive species.

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•Washington Department of Ecology, Aquatic Plant Management website. http://www.ecy.wa.gov/programs/wq/plants/management/index.html

Photo and illustration credits:

Page 37: Boat wash station; William Haller, University of Florida Center for Aquatic and Invasive Plants
Page 39: Benthic barrier; William Haller, University of Florida Center for Aquatic and Invasive Plants
Page 40: Drawdown; University of Florida Center for Aquatic and Invasive Plants (photographer unknown)

Chapter 7: Mechanical Control of Aquatic Weeds

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Introduction

The term "mechanical control" as used in this chapter refers to control methods that utilize large power-driven equipment. The simplest method of mechanical control might be the dragging of an old bedspring or other heavy object behind a boat to rip up and remove submersed weeds from a beach used for swimming. Mechanical control has been practiced in the US for over a century and almost every engineer has a conceptual idea of how to build the "perfect aquatic weed harvester." One major obstacle to designing a universal mechanical harvester is the diversity of plants and environments where the equipment will be employed. This has led to the development – and ultimate abandonment– of a plethora of various types of equipment throughout the years. Primary factors to be considered when selecting a mechanical control method are the types of weeds to be controlled and the habitats they occupy.

Wetland or emergent weeds

Wetland habitats are typical marsh ecosystems with periodically inundated soils, a high water table and/or water depths of up to two feet. Emergent plants such as phragmites (Chapter 15.11), purple loosestrife (Chapter 15.12), cattails and other wetland plants are common in these areas. Mechanical control is employed on a very limited basis in these "protected" habitats because access is often difficult and the destruction and alteration of protected wetlands in the US is highly regulated.

While there is very limited mechanical weed control conducted in wetlands, the mechanical control method most commonly employed by land managers is mowing. For example, dense stands of phragmites may be mowed during dry seasons or under drought conditions to provide temporary control. Also, chain saws and hand-pulling have been used in wetlands of southern Florida for control of melaleuca trees and seedlings, respectively. Ducks Unlimited and other resource agencies have used dredges and choppers of various types to reclaim or restore wetlands, but the primary purpose of these activities is not solely weed control. Overall, mechanical weed control is rarely used for invasive species management in wetlands and shallow-water areas due to the likelihood of creating significant environmental damage.

Floating weeds

Most mechanical weed control occurs in water greater than 2 feet deep and the type of plant to be controlled (floating or submersed) must be taken into consideration when selecting a mechanical control method. Floating plants should be evaluated separately from submersed plants because floating plants produce 10 to 20 times more biomass than submersed plants – biomass that has to be chopped, picked up or otherwise moved away from the harvesting site. For example, the standing crop or biomass of an acre of undisturbed waterhyacinth (Chapter 15.7) can weigh 200 to 300 tons per acre, whereas an acre of hydrilla (Chapter 15.1) or Eurasian watermilfoil (Chapter 15.2) can weigh only 10 tons or less per acre. Most mechanical harvesters are able to pick up and transport less than 5 tons of biomass per load, so there is a huge difference in the time, effort and expense required to mechanically harvest floating plants compared to submersed aquatic weeds.

Two additional problems associated with floating plants are their ability to move by wind or water currents and their location in lakes and rivers. For example, there may be only one access point where plants can be loaded onto trucks for disposal. Plants may initially be located close to the work site, but on another day – after a change in wind direction – plants may be on the other side of the lake and will need to be transported a long distance before they can be off-loaded. Also, floating plants are often blown into shallow waters along shorelines, which may be lined with cypress or willow trees. Most harvesters cannot work in water less than 2 feet deep and cannot navigate in and among trees, rocks or stump-fields in flooded reservoirs.

Submersed weeds

Mechanical harvesting of submersed weeds, primarily curlyleaf pondweed (Chapter 15.3) and Eurasian watermilfoil, has been utilized in the Northeast and Midwest. The shallow shores of even very deep lakes in these regions often support the growth of these submersed weeds and multiple harvests provide control during the recreational season. Governmental entities (including state, county and local governments) have subsidized weed removal from public lakes in some locations to maintain high use areas and to promote tourism and general utilization of the water resource. In other areas, lake associations and groups of homeowners often hire aquatic management companies for weed removal services. Although mechanical harvesting is often used in northern lakes to control submersed weeds, this method has less utility in southern states due to longer growing seasons and much larger-scale coverage of weeds in the shallow lakes and reservoirs more commonly encountered in the Southeast.

Examples of mechanical equipment

Cutter boats have been used in the US in one form or another for decades. For example, a small barge with a steam engine powered an underwater sickle bar mower in the Upper Chesapeake Bay/Potomac River area at the turn of the century. Submersed plants cut by the barge floated from the harvested area via river and tidal currents. Also, the US Army Corps of Engineers built sawboats in the early 1900s for use in navigable waters of Louisiana and Florida. These boats had gangs of circular saws mounted about an inch apart on a spinning shaft that was mounted at the bow of the boat and only penetrated the top inch or two of the water. These sawboats chopped up waterhyacinth, alligatorweed and grasses which formed intertwined mats of vegetation. The chopped vegetation was allowed to flow downstream or to salt water. Cutter boats have been used more recently to clear navigation channels, but this equipment is not usually used in lakes and non-flowing systems because most cut weeds float and survive for long periods of time. Fragments such as these can establish in other parts of the water body or wash up on swimming beaches. Cutter boats create large amounts of fragments and vegetative cuttings, so the ability of the target weed to spread and grow from fragments should be evaluated before cutter boats are employed as a primary mechanical control method.

Shredding boats are used to control emergent and floating plants. The most common type of shredder is the "cookie cutter," which consists of two spinning blades (3 to 4 feet wide) that are mounted behind a steel hood on the front of a small but powerful barge. The boat is propelled by hydraulically raising and lowering the blades and changing the direction of the blades (see www.texasharvesting.com). Recently, bow mounted high-speed flail mower blades have been tested for chopping and shredding floating and emergent plants. As with other mechanical control equipment, shredder boats are very specialized pieces of equipment, are non-selective and create many plant fragments. However, they work well when used in the areas for which they are designed and are frequently used in wetland restoration projects, where removal of cut vegetation is too expensive or not feasible.

Rotovators are highly specialized large aquatic rototillers. The rotovator head is lowered into the lake or river bottom and "tills" the sediments, which chops up and cuts loose submersed plants. A floating boom is usually placed around the work area while the rotovator spins on the lake bottom; uprooted plants float to the surface and are removed from along the barrier by hand or mechanical means. Rotovators have been used mostly in the Pacific Northwest, where the submersed weed Eurasian watermilfoil grows in rocky bottom areas and roots in the shallow soil between and among small rocks. The rotovator head moves the rocks around and uproots the weeds from the shallow soils and rock crevasses.

Dredges are not usually used for aquatic weed control due to high costs associated with their operation, but weed control can be a benefit of dredging that is done for other reasons. Shallow ponds and lakes that have filled with silt and organic matter over time may only be 3 to 4 feet deep and provide an ideal environment for excessive growth of submersed weeds and native plants such as cattail and waterlily. If the water depth of the pond is increased to 6 to 10 feet by dredging, it is unlikely that emergent plants such as cattail will continue to grow. However, submersed weeds will almost certainly still infest the pond if water depth and clarity requirements for growth of the weeds are met.

Harvest and removal harvesters are the most widely used types of equipment employed for mechanical control in the US. The first machines were developed in the 1950s by a Wisconsin company to harvest Eurasian watermilfoil and curlyleaf pondweed from the edges of the hundreds of lakes in the Upper Midwest. These lakes are generally deep in the middle and aquatic weeds naturally grow in the shallow littoral areas, which receive intensive use for swimming and docking.

Harvest and removal harvesters are powered by side-mounted paddle wheels which operate independently in forward or reverse. As a result, these harvesters are highly maneuverable around docks and boat houses. Also, the machines can operate in as little as 12 to 18 inches of water. These harvesters cut plants off at depths of 5 feet and in swaths 8 feet wide with a hydraulically operated cutter head and convey the cut plants into a storage bay on the harvester. When the harvester is full, it offloads harvested plants onto a transport barge by conveyer belts and the transporter takes the vegetation to shore, where it is dropped onto a conveyor to elevate the load to a truck for disposal. If you have read this carefully, you have counted four pieces of equipment: a harvester, a transporter, a shore conveyer and a truck. All this equipment may not be necessary, as mechanical harvesting is obviously tailored to a particular situation and is very site-specific. Also, some harvester trailers have been modified to allow them to transport cut weeds to the disposal site. This system or a setup with similar equipment has been used for 50 years in lakes from New England to California, but is mostly employed in northern lakes where one or two harvests during spring and summer can provide weed-free conditions for the seasonal summer use of these lakes.

Advantages and disadvantages

There are many advantages to mechanical harvesting. These include:

- Water can be used immediately following treatment. Some aquatic herbicides have restrictions on use of treated water for drinking and irrigation. Also, plants are removed during mechanical harvesting and do not decompose slowly in the water column as they do after herbicide application. In addition, oxygen content of the water is generally not affected by mechanical harvesting, although turbidity and water quality may be affected in the short term.

- Nutrient removal is usually insignificant because only small areas of lakes (1 to 2%) are typically harvested; however, some nutrients are removed with the harvested vegetation. It has been estimated that aquatic plants contain less than 30% of the annual nutrient loading that occurs in lakes.

- The habitat remains intact because most harvesters do not remove submersed plants all the way to the lake bottom. Like mowing a lawn, clipped plants remain rooted in the sediment and regrowth begins soon after the harvesting operation.

- Mechanical harvesting is site-specific because plants are removed only where the harvester operates. If a neighbor wants vegetation to remain along his or her lakefront, there is no movement of herbicides out of the intended treatment area to impact the neighbor's site.

- Herbicide concerns remain widespread despite extensive research and much-improved application, use and registration requirements that are enforced by regulatory agencies (Appendix A). Mechanical harvesting, despite some environmental concerns (as outlined below), is perceived to be environmentally neutral by the public.

- Utilization of harvested biomass is thought by many to be a means of offsetting the relatively high costs and energy requirements associated with mechanical harvesting. Unfortunately, no cost-effective uses of harvested vegetation have been developed, despite much research examining the utility of harvested plant material as a biofuel, cattle feed, soil amendment, mulch or even as a papermaking substrate. As much as 95% of the biomass of aquatic plants is water, so 5 tons of Eurasian watermilfoil yields only 500 pounds of dry matter. In addition, cut plants in northern lakes are only available for 3 to 4 months of the year.

The easiest way to highlight the disadvantages of mechanical harvesting is to point out that major producers of farm equipment (for example, John Deere or New Holland) do not mass-produce equipment designed for the mechanical harvesting of aquatic weeds. Farmers are famous for efficiently cutting, harvesting and moving hay, corn and grain crops; they constitute a large market and specialized equipment is available to them. On the other hand, the demand for aquatic weed harvesters is very small, so the equipment associated with these operations is often custom-made and expensive. Other disadvantages include:

• The area that can be harvested in a day depends on the size of the harvester, transport time, distance to the disposal site and density of the weeds being harvested. These factors can result in a wide range of costs. The cost of harvesting is site-specific, but mechanical harvesting is generally more expensive than other weed control methods due to the variables noted above and the generally high capital outlay required to purchase equipment that may only be used for 3 or 4 months per year.

• Mechanical harvesters are not selective and remove native vegetation along with target weeds. However, this is probably not a significant disadvantage since native plants and weeds will likely return by the next growing season, if not sooner.

• By-catch, or the harvesting of nontarget organisms such as fish, crayfish, snails and frogs along with weeds, may be more of a concern, but the degree or extent of harvesting should be considered. Research on fish catch during mechanical harvesting of submersed vegetation has shown that 15 to 30% of some species of fish can be removed with cut vegetation during a single harvest. If the total area of a lake that is harvested is 1, 5 or 10% of the lake's area, this will likely be of little consequence. However, if the management plan for a 10-acre pond calls for complete harvests 3 times per year, then the issue of by-catch of fish deserves more consideration.

• Regrowth of cut vegetation can occur quickly. For example, if hydrilla can grow 1" per day as reported, a harvest that cuts 5 feet deep could result in plants reaching the water surface again only two months after harvesting. Speed of regrowth depends on the target weed, time of year harvested, water clarity, water temperature and other factors.

• Floating plant fragments produced during mechanical harvesting can be a concern because most aquatic weeds can regrow vegetatively from even small pieces of vegetation. If an initial infestation of aquatic weeds is located at a boat ramp, care should be taken to minimize the spread of fragments to uninfested areas of the lake by maintaining a containment barrier around the area where mechanical harvesting will take place. On the other hand, if a lake is already heavily infested with a weed, it is unlikely that additional fragments will spread the weeds further. However, homeowners downwind of the harvesting site may not appreciate having to regularly rake weeds and floating fragments off their beaches.

• Disposal of harvested vegetation can be an expensive and difficult problem after mechanical harvesting. Research during a project in the 1970s on Orange Lake in Florida compared the costs of in-lake disposal to the transport, off-loading and disposal of cut material at an upland site. As water levels on Orange Lake decreased during a drought period, the mechanical harvester was allowed to off-load cut vegetation along the shoreline among emergent vegetation instead of transporting harvested plants to the shore for disposal. The cost of in-lake disposal reduced the per-acre cost by about half when compared to transporting the vegetation to shore, loading it into a truck and disposing of the plant material in an old farm field.

• Some lakes or rivers may not be suitable for mechanical harvesting. If there is only one public boat ramp on a lake and it is not close to the area to be harvested, the costs of moving the cut vegetation from the harvester to shore will add significantly to the cost of the operation. Harvesters are not high-speed machines and move at 3 to 4 mph, so if a river flows at 2 mph and the harvester has to travel upstream to the off-loading site, well, do the math! Off-loading sites usually must have paved or concrete surfaces because the weeds are wet and an unpaved off-loading site can quickly become a quagmire.

Recent advances in deep-water harvesting

The rising cost of herbicides for hydrilla control and the development of fluridone-resistant populations of hydrilla in Florida lakes served as the stimulus for a multi-agency evaluation of improved mechanical control techniques for hydrilla control during the early 2010s (see www.fapms.org/aquatics/2012fall.pdf). Improved efficiency and reduced costs associated with mechanical harvesting would likely result if: 1) harvesters were larger, since this would reduce the number of trips and transport time needed to offload harvested material; and 2) deeper harvesting was possible, since this would reduce weed biomass in deeper waters, resulting in longer intervals between harvesting events because weeds would require more time to regrow to problematic levels.

To test this theory, a 70-foot harvester with a cutter head capable of harvesting weeds in water as deep as 10 feet was developed by a commercial firm. The harvester was also equipped with a GPS tracking unit to allow the operator to harvest plants that are difficult or impossible to see from the operator's position on the harvester. This equipment was used in an early-season (March) operation to remove hydrilla that was 3 to 6 feet tall and growing in 8 to 9 feet of water and allowed harvesting of 2 to 4 acres per hour. "Topped-out" or surface-matted hydrilla can weigh as much as 14 tons (fresh weight) per acre, but this low-growing hydrilla, which was harvested from the soil line up through the water column, averaged only 1,000 pounds per acre. Fish by-catch was greatly reduced during this operation compared to previous operations in surface-matted hydrilla because: 1) oxygen levels were consistent throughout the water column due to less dense weed populations than those encountered later in the season, so fish did not preferentially inhabit weed beds; and 2) the relatively low weed density entangled fewer fish, so fish could escape the harvester. This early-season deep-water harvesting operation had a negligible impact on water quality because the harvester's propulsion unit was farther away from the lake bottom and sediments were not disturbed as they would be in shallower water. In addition, control was achieved for 5 to 7 months; this is a decided improvement over the 2 to 3 months of control provided by shallow-water harvesting and could allow longer intervals between harvesting, which would significantly reduce the costs associated with mechanical harvesting. Additional trials are planned, but it appears that the strategy of using a GPS-assisted larger harvester to manage less dense weed infestations in deeper water may significantly increase the efficiency of mechanical harvesting of submersed weeds.

Summary

This discussion is not intended to include all the machines that are available for mechanical control of aquatic weeds and it is likely that new ideas and equipment will be developed as time passes. It is important to remember that each site and each weed has characteristics that may require a particular type of mechanical harvester and may preclude the use of other mechanical methods of control. There is a vast repository of information available on the internet and the best source of information is the conservation or regulatory agency in your state. In fact, most states require that permits for mechanical harvesting be obtained before work can begin. For a further discussion of mechanical control, photos of equipment and a list of equipment manufacturers, please visit http://plants.ifas.ufl.edu/guide/mechcons.html.

For more information:

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•McGehee JT. 1979. Mechanical hydrilla control in Orange Lake, Florida. Journal of Aquatic Plant Management 17:58-61.

•http://www.ecy.wa.gov/Programs/wq/plants/management/aqua026.html

•http://www.co.thurston.wa.us/stormwater/Lakes/Long%20Lake/Long_Harvesting.htm

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Page 43: Mower; William Haller, University of Florida Center for Aquatic and Invasive Plants

Page 45: Cutter boat; William Haller, University of Florida Center for Aquatic and Invasive Plants

Page 46: Harvester; William Haller, University of Florida Center for Aquatic and Invasive Plants

Page 48: Conveyor; Jeff Schardt, Florida Fish and Wildlife Conservation Commission

Chapter 8: Introduction to Biological Control of Aquatic Weeds

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Introduction

There are many herbivores or plant-eating animals in the aquatic environment, including moose, muskrat, turtles, fish, crayfish, snails and waterfowl. These animals are general herbivores and may prefer to eat certain types of plants, but do not rely on a single plant species as a primary food source. Although these animals do consume aquatic plants and therefore reduce the growth of some species, they generally do not have a significant impact on overall plant growth because they feed on many different plants and are not considered biological control agents. Biological control (also called biocontrol) is broadly defined as the planned use of one organism (for example, an insect) to control or suppress the growth of another organism such as a weedy plant species. Biocontrol of weeds is primarily the search for, and introduction of, species-specific organisms that selectively attack a single target species such as an exotic weed. These organisms may be insects, animals or pathogens that cause plant diseases, but most biocontrol agents are insects. Biocontrol has been studied and used for more than a century and has developed into a complicated and technical science based on a number of principles that will be discussed in this chapter. Two different approaches are currently used in the biocontrol of aquatic weeds: classical (importation) and non-classical (augmentation, conservation).

Classical biocontrol is by far the most common biological control method and typically involves the introduction of natural enemies from their native range to control a nonnative invasive plant. The excessive growth of a weed in its new habitat is due in part to the absence of natural enemies that normally limit or slow the growth, reproduction and spread of the weed in its native range. Classical biocontrol seeks to reunite an invasive plant with one or more of its coevolved natural enemies to provide selective control of the weed. Thus, classical biocontrol can be defined as the planned introduction and release of nonnative target-specific organisms (usually arthropods, nematodes or plant pathogens) from the weed's native range to reduce the vigor, reproductive capacity or density of the target weed in its adventive (new or introduced) range.

Classical biocontrol offers several advantages over other weed control methods. It is relatively inexpensive to develop and use compared to other methods of weed control. Classical biocontrol provides selective, long-term control of the target weed and because biocontrol agents reproduce, they will usually spread on their own throughout the infested area. Some of the strengths of classical biocontrol also contribute to its shortcomings. For example, it may not be possible to find a biocontrol agent that effectively controls a single weed and selectively attacks only that particular weed. When potential biocontrol agents are identified, their establishment and suppression of the target weed in the introduced area are not guaranteed. Even if biocontrol agents do successfully establish in their introduced areas, control is not immediate and agents may require many years to have a major impact on target weeds. Finally, once a biocontrol agent is established, it cannot be recalled if desirable nontarget species are affected by the agent.

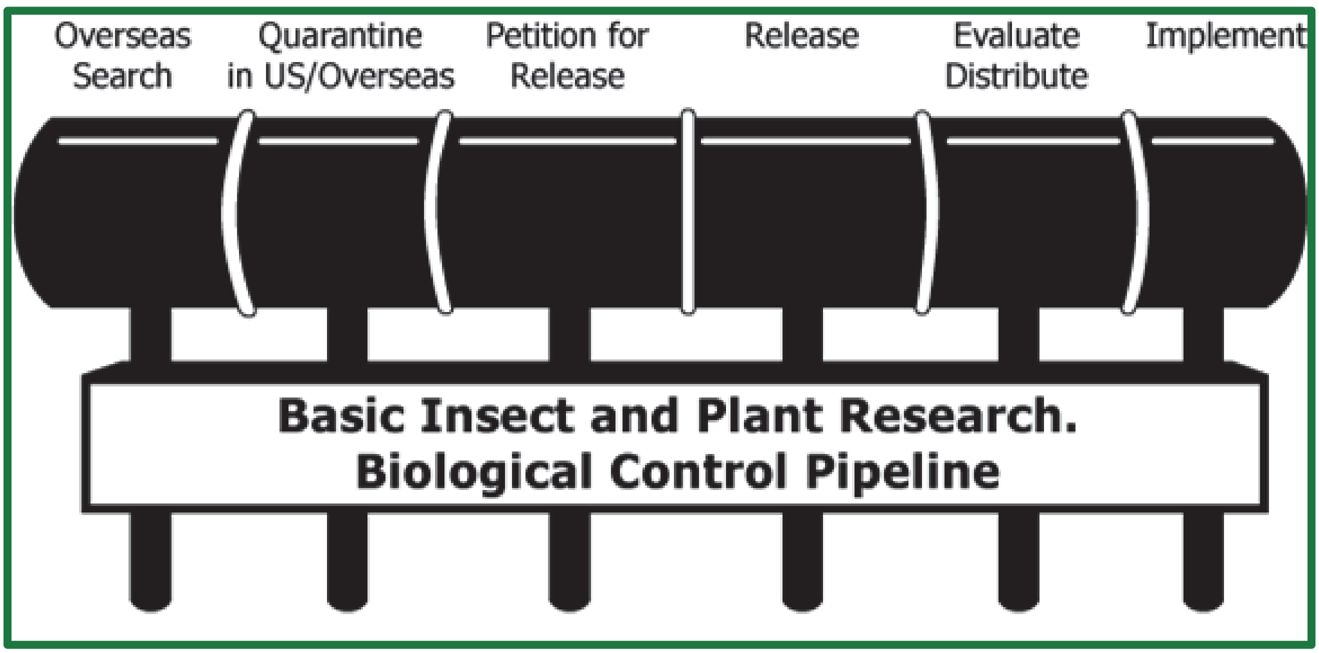
Non-classical biocontrol involves the mass rearing and periodic release of resident or naturalized nonnative aquatic weed biocontrol agents to increase their effectiveness. Savvy home gardeners employ this approach when they purchase ladybird beetles to control aphids (insects that are serious pests of fruits, vegetables and ornamentals) in their home gardens. Augmentative or repeated releases of native or naturalized insects have occasionally been used for suppression of alligatorweed, waterhyacinth (Chapter 15.7), hydrilla (Chapter 15.1) and Eurasian watermilfoil (Chapter 15.2).

The "new association" approach is a variation of classical biocontrol. **New association biocontrol** differs from classical biocontrol in that the natural enemies or biocontrol agents have not played a major role in the evolutionary history of the host plant and are therefore considered new associates. Because organisms used in the new association approach are not entirely host-specific, this approach is appropriate only in cases where the target weed has few or no closely related native relatives in the area of introduction.

A good example of the new association approach is the milfoil weevil (*Eurychiopsis lecontei*), which is native to North America and attacks native species of milfoil (*Myriophyllum* spp.) in the US and Canada. Recent studies have shown that milfoil weevils reared on the introduced weed Eurasian watermilfoil (*Myriophyllum spicatum*) not only develop faster and survive better on the exotic invasive milfoil, but also preferentially attack the nonnative weed species over the native northern watermilfoil (*M. sibiricum*), its natural host plant. This phenomenon was unexpected, unplanned and unusual. Many aquatic resource managers are currently evaluating this natural occurrence to determine how best to include this weevil in weed control programs.

Procedures in a Classical Weed Biocontrol Project

Weed biocontrol scientists (most of whom are entomologists or pathologists) develop and refine procedures for locating, screening, releasing and evaluating biocontrol agents. All countries



currently conducting weed biocontrol projects follow this protocol in one form or another to ensure that candidate organisms are safe to introduce. The normal process in a classical biocontrol program is often referred to as the "pipeline." The pipeline consists of the following series of well-defined steps:

- Step 1: Target selection. Ideal targets for biocontrol are invasive nonnative aquatic plants with no closely related native plants in their introduced ranges. Scientists read the literature associated with the target weed to learn where the weed came from (geographic origin), what desirable plants are closely related to the weed and to identify potential natural enemies.

- Step 2: Overseas and domestic surveys. Scientists visit the native range of the target weed to search for natural enemies that may affect and slow the growth of the weed. They evaluate how the target weed is damaged by organisms in its native range to determine if these organisms may be useful as biocontrol agents for the target weed in its introduced range. Another predictor of success is past performance; if a biocontrol agent has been successful in controlling a weed in some countries, there is a high probability that it will be successful in other countries as well. Scientists also conduct surveys in the weed's introduced range (domestic surveys) to avoid introducing biocontrol agents that are already established but ineffective.

- Step 3: Importation and quarantine studies. If an organism attacks only the exotic weed, and not desirable species, scientists request permission from the US Department of Agriculture to import the organism to the US for host range testing. Once permission for importation is granted, the potential biocontrol agent is brought to the US and placed in an approved quarantine laboratory where it cannot escape and is carefully studied to ensure it will not harm desirable species such as crops and native plants.

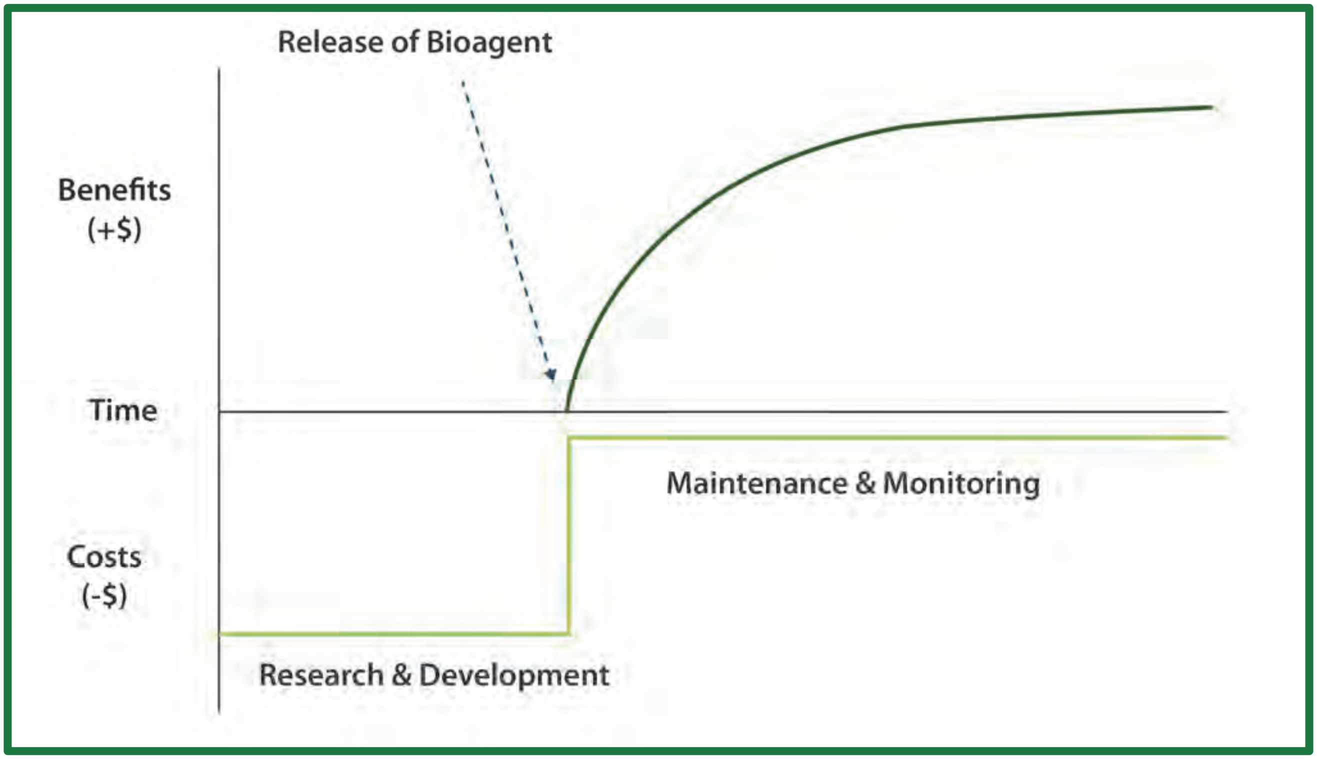
- Step 4: Approval for release. The results of quarantine studies are forwarded to the appropriate federal and state agencies, who determine whether the organism is safe to release. These independent agencies may request that additional testing be done to evaluate the effect of the organism on additional native plants, especially threatened or endangered species, as well as related plants not included in the original quarantine studies.

- Step 5: Release and establishment. Once the biocontrol agent is shown to pose minimal risks to desirable native, ornamental and crop plants, permits are issued and large numbers of the biocontrol agent are reared. This ensures that population densities will be high enough to allow breeding colonies of the agent to establish in the field. Scientists then release the biocontrol agent in multiple locations to increase the likelihood of successful establishment.

- Step 6: Evaluation. Scientists monitor all introduced biocontrol agents after field release to confirm establishment and dispersal of the agent. Multiple releases of the organism may be necessary initially to maintain populations that are adequate for control of the weed species. Studies are also conducted to determine the effect of the biocontrol agent on the target weed as well as on additional nontarget plants.

•Step 7: Technology transfer. Resource managers are trained in the identification and use of the biocontrol agent. Scientists also collaborate with those using the biocontrol agent to determine the best methods to integrate biocontrol with other weed control methods.

Successful biocontrol programs are expensive at the beginning and can take a long time to develop, but biocontrol can reduce the need for other weed control methods such as herbicides and mechanical harvesting. Because classical biocontrol can provide selective, long-term control of a target weed and biocontrol agents naturally spread by reproducing, the use of biocontrol results in the reduction or elimination of costs for other aquatic weed control methods.



Safety – what has to be done to introduce a biocontrol agent?

Host specificity is fundamental to biological weed control because it ensures that an introduced agent will not damage desirable plants. Host-specific, coevolved natural enemies are considered good candidates for use as biocontrol agents because they are unable to reproduce on plants other than their weedy hosts. In addition, these types of organisms have proven to be the safest to introduce because they are least likely to damage nontarget species. Because host-specific natural enemies reproduce only when they have access to their host plants, their populations are limited by availability and abundance of the target weed.

Potential biocontrol agents are first tested for effectiveness and host specificity in their native range, then promising candidates are brought to quarantine laboratories in the US for final host range testing to determine whether the organism can live and reproduce on native plants. Before scientists can release an agent into the US for classical biocontrol of an invasive aquatic plant, the potential agent must undergo rigorous testing in quarantine to ensure it will only survive on the weed species and will not harm nontarget species. The potential biocontrol agent is offered a series of carefully chosen plants in two different types of tests to determine if the agent is safe to release. In no-choice tests, the agent is given access only to a nontarget plant to determine if it will attack the nontarget plant if the agent's host plant (the target weed) is unavailable. In multiple-choice tests, the agent is offered the target weed and at least one nontarget plant to determine whether the agent damages only the target weed. Nonnative biocontrol agents can only be released if these tests show that the agent requires the host plant to survive and reproduce and that it will not attack desirable nontarget plants.

Selecting organisms as candidates for classical biocontrol is a complicated and lengthy process because scientists must identify natural enemies that have developed a high degree of specificity with their weedy host plants. According to established guidelines, no potential biocontrol agent can be introduced into a new environment before its host range is determined. Multiple screening tests are usually required to identify the host range of the agent and scientists must conduct a number of host range tests in the field and laboratory (egg laying, larval development and feeding by adults) to determine whether a biocontrol agent requires the presence of the weedy host plant to survive. Candidate organisms that are able to live and reproduce without access to their weedy host fail the host specificity requirement; they are then dropped from further consideration and quarantined populations are destroyed.

The review process – why does it take so long to release a biological control insect?

The US Department of Agriculture's Animal and Plant Health Inspection Service, Plant Protection Quarantine permitting unit (hereafter referred to as APHIS) is responsible for approving the release of any biocontrol agent in the US. The Plant Protection Act of 2000 gives APHIS the authority to regulate "any enemy, antagonist or competitor used to control a plant pest or noxious weed." Scientists must apply for a permit from APHIS before they can import a potential biocontrol agent into the US for host specificity testing and approved biocontrol agents must be sent directly to a high-security quarantine facility upon entry into the US. There are a number of secure quarantine facilities located throughout the US that are specifically designed and constructed for biocontrol research on aquatic and terrestrial weeds.

After host specificity testing is completed, a permit must be obtained from APHIS before the biocontrol agent is released in the field. A multi-agency Technical Advisory Group for Biological Control Agents of Weeds (TAG) reviews information submitted by the requesting scientist to APHIS. TAG members review test plant lists for weed biocontrol projects, advise weed biocontrol scientists, review petitions for field release of weed biocontrol agents and provide APHIS with recommendations on the proposed release.

In addition to submitting a release petition to TAG and APHIS, scientists contact the Department of the Interior to ensure that threatened and endangered species are included in their test plant list. Release of nonnative weed biocontrol agents also requires compliance with the Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA). Scientists must complete an Environmental Assessment (EA) document that outlines the potential impact of the biocontrol agent on the environment in order to comply with the NEPA. The EA provides the public with possible positive and negative environmental impacts that might occur if the new biocontrol agent is released in the US. Scientists must also submit to the US Fish and Wildlife Service a Biological Assessment (BA) document in order to comply with the ESA. The review process is designed in this manner to ensure that there is little chance the introduced biocontrol agents will become pests themselves. Once a weed biocontrol agent is released, several years may be required for the organism to establish and impact the target weed. Scientists continually monitor dispersal of the agent, collect data on its effectiveness to the target weed and also monitor the agent's effect (if any) on nontarget plants during this time.

What is considered a success?

Successful biocontrol of an aquatic weed is a function of the biocontrol agent's capacity to reproduce on individual plants and to build populations large enough to damage the weed's population. However, high population densities of a biocontrol agent do not necessarily guarantee success and effective biocontrol may only occur when the weed is stressed concurrently by local climatic conditions, competing plants or other natural enemies.

In general, insect biocontrol of aquatic weeds in the US has been successful since it was first used to control alligatorweed in 1964. Insects have provided varying levels of control (from complete control to suppression of growth) of the aquatic form of alligatorweed and of waterhyacinth in most areas where insect biocontrol has been attempted. The high success rate achieved by these projects may be correlated with the growth form of the weeds, their susceptibility to disease-causing pathogens, the fluid nature of the aquatic environment, the organisms used as biocontrol agents, or a combination of these factors. For instance, waterhyacinth and the aquatic form of alligatorweed produce floating mats, a growth habit that makes them susceptible to wave action and currents that are unique to aquatic environments. Also, reproduction of these weeds is due primarily to rapid vegetative growth, which results in clonal populations with little or no genetic diversity. Since many plant defenses against diseases and insects (including biocontrol agents) are determined by the genetic composition of a plant, the entire population of a clonally reproducing species would likely react to a biocontrol agent in the same manner; that is, if one plant is damaged by the biocontrol agent, the entire population is likely to be damaged by the agent as well. Waterhyacinth and the aquatic form of alligatorweed also are highly susceptible to secondary infection, so plants that have been injured by insects or disease rot and disintegrate very rapidly. Finally, beetles – especially weevils – have been responsible for most successful biocontrol programs. Adults of these insects tend to remain above the water, which may reduce fish predation, whereas larvae often feed inside the plant. These habits allow them to maintain high density populations in the environment. A number of successful weed biocontrol programs have utilized members of the insect group *Coleoptera*; in fact, the majority (greater than 75%) of insects released thus far for biocontrol of aquatic plants are weevils and beetles.

Defining success in biocontrol of weeds is usually subjective and highly variable. A project may be considered successful in an ecological sense when a biocontrol agent successfully establishes in an area and reduces the target weed's population. However, the severity of damage inflicted by the biocontrol agent may not result in the level of control desired by lake managers, boaters and homeowners. Recently, a clear distinction has been made between "biological success" and "impact success." Biocontrol agents can be biologically successful (they establish and sustain high population densities on the target weed), but may not realize impact success (they do not provide the desired level of control or impact on the weed).

The use of terms that define success (such as complete, substantial or negligible) in a biocontrol program may not take into account variations in time and space. For example, in the southeastern United States where the alligatorweed flea beetle has been introduced, biocontrol success can range from complete to negligible depending on the season, geographic area and habitat (Chapter 9). However, these terms can be useful from an operational perspective since they describe the current success level of biocontrol efforts and help managers to determine which other control measures (e.g., harvesters, aquatic herbicides) must be used to achieve the desired level of weed control. The advantage of this system is that it describes success in practical terms that are more readily understood by aquatic plant managers and the public. For example, biocontrol is defined as complete when no other control method is required, substantial when other methods such as herbicides are still required but at reduced levels and negligible when other control methods must be used at pre-biocontrol levels to manage the weed problem.

Summary

Biocontrol historically has been a major component of integrated pest management programs for terrestrial insect and weed control and can be an effective tool in the aquatic weed manager's arsenal as well. Classical biocontrol, which relies on importation of natural enemies from a weed's native home, may be useful to control an exotic invasive species that thrives when introduced to an area that lacks the natural enemies responsible for keeping the weed in check in its native range. The use of host-specific biocontrol agents allows management of populations of weedy species while leaving nontarget native plants unharmed. Successful biocontrol programs are often expensive and time-consuming to develop, but if successful can provide selective, long-term control of a target weed. Although a number of types of organisms – including disease-causing plant pathogens, insects and grass carp – have been studied for potential use as biocontrol agents, the greatest successes in aquatic systems have been realized with insects (Chapter 9) and grass carp (Chapter 10).

For more information:

•Biological control for the public. http://everest.ento.vt.edu/~kok/Text_frame1.htm

•Biological control of weeds – it's a natural!
http://www.wssa.net/Weeds/Tools/Biological/BCBrochure.pdf

•Biological control of weeds: why does quarantine testing take so long?
http://ipm.ifas.ufl.edu/applying/methods/biocontrol/quarantinetest.shtml

•Harley KLS and IW Forno. 1992. Biological control of weeds: a handbook for practitioners and students. Inkata Press, Melbourne, Australia.

•How scientists obtain approval to release organisms for classical biological control of invasive weeds.
http://edis.ifas.ufl.edu/IN607

•Mentz KM. 1987. The role of economics in the selection of target pests for a biological control program in the South-west Pacific, pp. 69-85. In P Ferrer and DH Stechman (eds.), Biological control in the South-west Pacific. Report on an international workshop, Vaini, Tonga, 1985. Government Printing Office, Tonga.

• Plant management in Florida waters – biological control
http://plants.ifas.ufl.edu/guide/biocons.html.

•Smith RF and R van den Bosch. 1967. Integrated control, pp. 295-340. In WW Kilgore and RL Doutt (eds.). Pest control – biological, physical and selected chemical methods. Academic Press, New York.

•US Army Corps of Engineers Aquatic Plant Information System
http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm

Photo and illustration credits:

Page 52: Biocontrol pipeline; Joshua Huey, University of Florida Center for Aquatic and Invasive Plants
Page 54: Biocontrol graph; Harley and Forno, 1992

Chapter 9: Insects for Biocontrol of Aquatic Weeds

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Introduction

Biocontrol of aquatic weeds with insects has resulted in the successful establishment of many potential biocontrol insects since it was first attempted in the US against alligatorweed in 1964. Aquatic weeds have historically been a more serious problem in the southern US due to the moderate climate and shallow lakes in these regions where weeds often cover large areas. Consequently, the greatest body of research on biocontrol has focused on weeds of the southern US. The following section describes in detail the relationship of particular biocontrol insects introduced into the US and their target weeds.

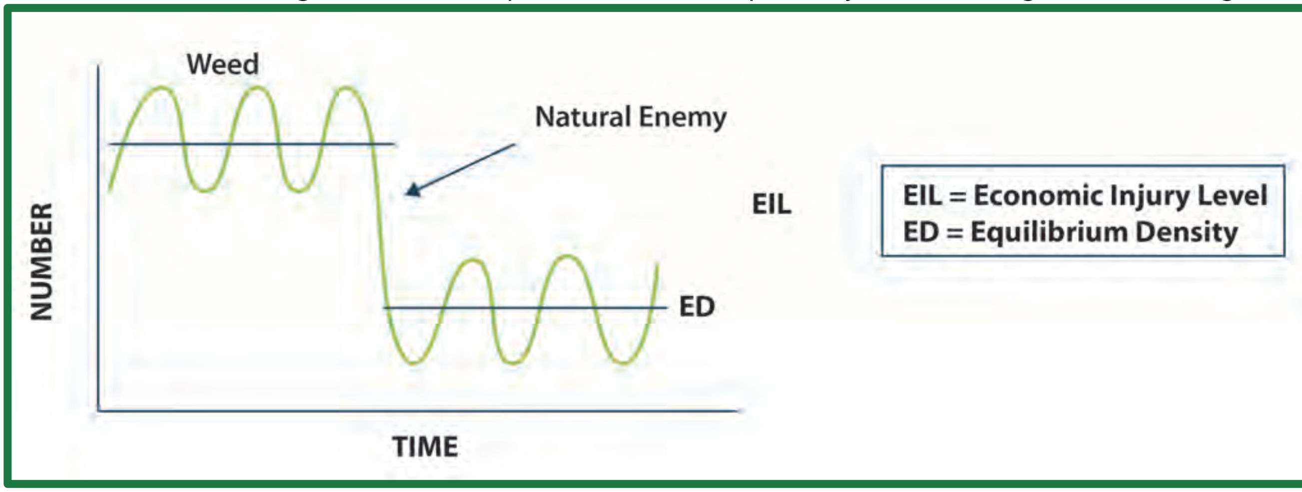
Alligatorweed (*Alternanthera philoxeroides*)

(see http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm for more information)

Enemy	Type	Origin (date)	Success	Comments
Agasicles hygrophila	Beetle	Argentina (1964)	Complete (south); Negligible (north)	Found throughout the southern 2/3 of the range of alligatorweed in the US where it provides almost complete control
Amynothrips andersoni	Thrips	Argentina (1967)	Negligible	Attacks terrestrial plants more than the other species
Arcola (=Vogtia) malloi	Moth	Argentina (1971)	Negligible	Most important control agent in the upper Mississippi valley

If this manual had been written in the 1960s and 1970s, alligatorweed (introduced in the late 1800s) would have been included as one of the worst weeds in the US in Chapter 15. The alligatorweed flea beetle (*Agasicles hygrophila*) was introduced in 1964 and has provided excellent control of the floating form of alligatorweed from southern Florida along the Gulf Coast to southern Texas. Unfortunately the alligatorweed flea beetle is not as cold-tolerant as alligatorweed and insect populations die out during severe winters in the central and northern parts of the Gulf states.

Alligatorweed remains a problem in areas such as central and northern Texas, Mississippi, Alabama, Georgia and the Carolinas. The alligatorweed flea beetle is self-sustaining in its southern range but not in the north. The US Army Corps of Engineers periodically collects and re-releases the beetle in northern areas during spring to reestablish northern populations. This is an example of combining augmentation with classical biocontrol. The alligatorweed flea beetle has eliminated the need for other forms of control in natural areas when it is well-established. The *Amynothrips* and *Arcola* insects also are established on alligatorweed; the *Amynothrips* attacks the terrestrial alligatorweed plants more than do the other species. However, control of alligatorweed is largely attributed to the alligatorweed flea beetle. Alligatorweed provides a good example of how a biocontrol agent controls its weedy host plant without completely eradicating the population of the weed. Alligatorweed grows quickly in spring and populations of the alligatorweed flea beetle increase as well, but lag behind development of the host plant. By the time alligatorweed has grown



enough to become problematic, the population of the alligatorweed flea beetle reaches a density sufficient to destroy most of the alligatorweed. The number of alligatorweed flea beetles then decreases, alligatorweed growth resumes and the cycle begins anew. This is a nearly perfect example of a highly successful insect biocontrol program that adequately controls an invasive aquatic plant. Furthermore, 40 to 50 years after their introduction, none of the three insects released to control alligatorweed have been found feeding on, reproducing on or otherwise affecting nontarget native species.

Waterhyacinth (Chapter 15.7)

(see http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm for more information)

Enemy	Type	Origin (date)	Success	Comments
Neochetina bruchi	Weevil	Argentina (1974)	Substantial	Widely distributed throughout the range of waterhyacinth in the US
Neochetina eichhorniae	Weevil	Argentina (1972)	Substantial	
Niphograpta albiguttalis	Moth	Argentina (1977)	Negligible	Prefers plants with short bulbous petioles
Orthogalumna terebrantis	Mite	USA (native)	Negligible	Produces characteristic dark stripes in the leaves; also attacks pickerelweed
Megamelus scutellaris	Bug	South America (2010)	Established	

Two *Neochetina* weevils and the *Niphograpta* stem-boring caterpillar have been released as biocontrol agents of waterhyacinth. The life cycle of the *Neochetina* weevils requires about 2 to 3 months to complete and is dependent on temperature. These weevils act on waterhyacinth by causing feeding damage that reduces the plant's ability to regenerate. Adult weevils produce characteristic rectangular feeding scars on the leaves, whereas larvae tunnel inside the leaf petioles to the crown or meristem where they damage new growth. Feeding damage also allows plant pathogens to invade the feeding scars and larval tunnels, which further weakens the plant. The life cycle of the *Niphograpta* caterpillar is completed in about 4 to 5 weeks. This insect prefers to attack smaller plants with bulbous petioles; petioles that are attacked often become waterlogged and die. However, the impact of the *Niphograpta* caterpillar has been difficult to evaluate because it causes tremendous damage for only a brief period and then disappears. The *Neochetina* weevils and the *Niphograpta* stem-boring caterpillar are established and occur almost everywhere waterhyacinth is distributed throughout the southern US. Growth of waterhyacinth is suppressed and vegetative reproduction is reduced, but other means of control are necessary in most areas.

Hydrilla (Chapter 15.1)

(see http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm for more information)

Enemy	Type	Origin (date)	Success	Comments
Bagous affinis	Weevil	India (1987)	Not Established	
Bagous hydrillae	Weevil	Australia (1991)	Not Established	
Cricotopus lebetis	Midge	Unknown (adventive)	Negligible?	Damages growing tips of hydrilla Also see http://edis.ifas.ufl.edu/IN211
Hydrellia balciunasi	Fly	Australia (1989)	Negligible	Found primarily in Texas
Hydrellia pakistanae	Fly	India (1987)	Negligible?	Widely distributed on dioecious hydrilla in the southeastern and south-central US
Parapoynx diminutalis	Moth	Asia (adventive)	Negligible	Causes localized occasional heavy damage to hydrilla
Ctenopharyngodon idella	Fish	China (1963)	Substantial	Throughout the US by permit (Chapter 9) Also see http://plants.ifas.ufl.edu/guide/grasscarp.html

Two *Bagous* weevils (one from India that attacks tubers and one from Australia that mines stems) have been introduced as biocontrol agents for hydrilla, but both have failed to establish. However, two *Hydrellia* flies (one from India and one from Australia) have become established. The fly *H. pakistanae* is widespread in the southern US, whereas *H. balciunasi* is localized in distribution. Populations of *Hydrellia* flies have not reached densities high enough to control hydrilla, possibly due to parasitism of the pupae by a native wasp or perhaps other environmental factors. The entire life cycle for both flies is completed in about 3 to 4 weeks, which should allow development of high insect populations. The adventive *Parapoynx* moth from Asia probably entered the US via the aquarium trade and was discovered in Florida feeding on hydrilla in 1976. The life cycle of *Parapoynx* is completed in 4 to 5 weeks; the moth was never studied or approved for release, but large populations of hydrilla are occasionally completely defoliated by the moth. The adventive naturalized nonnative *Cricotopus* midge has been associated with hydrilla declines in several Florida locations since 1992. The life cycle of *Cricotopus* is completed in 1 to 2 weeks and developing larvae of the midge mine the shoot tips of hydrilla, which severely injures or kills the plant's growing tips. Feeding damage changes the plant's structure or architecture by preventing new hydrilla stems from reaching the surface of the water column. Despite localized and occasionally severe impacts on hydrilla, none of these insects can cause damage significant enough to provide adequate control when used alone. Research to identify biocontrol agents for hydrilla continues due to the increasing spread of the species throughout the US, its development of resistance to the herbicide fluridone and the relatively high costs associated with other methods employed to control this weed.

Purple loosestrife (Chapter 15.12)

(see http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm for more information)

Enemy	Type	Origin (date)	Success	Comments
Galerucella calmariensis	Beetle	Germany (1992)	Substantial	Widely distributed throughout the range of purple loosestrife in the US
Galerucella pusilla	Beetle	Germany (1992)	Substantial	
Hylobius transversovittatus	Weevil	Germany (1992)	Substantial	
Nanophyes marmoratus	Weevil	France, Germany (1994)	Negligible?	

Two nearly identical *Galerucella* leaf beetles are responsible for most biocontrol of purple loosestrife; in fact, these beetles have reduced purple loosestrife infestations by 90% in several states, especially Oregon and Washington. Larvae feed on buds, leaves and stems of the plants and heavily defoliated plants are often killed by the feeding insects. The life cycle of the beetles is completed in about 6 weeks but there is only one generation per year, with pupation occurring in the soil if it is not continuously flooded. This low rate of reproduction is responsible for the lag time between introduction of the beetles and noticeable effects on the plants. Two weevils – the root-attacking *Hylobius* and seed-attacking *Nanophyes* – also contribute to the successful biocontrol of purple loosestrife. Larvae of *Hylobius* feed and develop in the tap roots and pupation occurs in the upper part of the root. Larvae require 1 to 2 years to complete their development and adults can live for several years. Adults of *Nanophyes* feed on young leaves or flowers and lay their eggs in flower buds. Pupation occurs inside the bud and larvae consume the flower buds; buds then fail to open and drop prematurely from the plant. Although the entire life cycle is completed in about 1 month, there is only 1 generation per year. Leaf-eating *Galerucella* beetles, root-attacking *Hylobius* weevils and seed-attacking *Nanophyes* weevils have only recently been introduced as biocontrol agents on purple loosestrife but appear to be very successful in reducing the growth, occurrence and competitiveness of this emergent weed.

Eurasian watermilfoil (Chapter 15.2)

(see http://www.invasive.org/eastern/biocontrol/6EurasianMilfoil.html for more information)

Enemy	Type	Origin (date)	Success	Comments
Acentria ephemerella	Moth	Europe (adventive)	Negligible?	All can cause declines to populations of Eurasian watermilfoil in localized areas of lakes. Results are difficult to predict.
Cricotopus myriophylli	Midge	China (adventive)	Negligible?	
Eurychiopsis lecontei	Weevil	US (native)	Substantial?	

Several insects have been found attacking Eurasian watermilfoil during overseas surveys, but none have been introduced to the US thus far. Recent declines in the abundance of Eurasian watermilfoil in some northern lakes have been attributed to the adventive *Acentria* moth and *Cricotopus* midge, as well as the native *Eurychiopsis* weevil. These insects are widely distributed throughout the range of Eurasian watermilfoil in North America and are found in all areas infested by the weed; as a result, it is difficult to assess their effectiveness as biocontrol agents. Larvae of the *Acentria* moth feed both in and on stems and leaves, which causes the leaves to drop off the plant. Females have reduced wings and are usually flightless and mating occurs in or on the water surface. Two generations are produced annually and pupae form on the stems. Larvae also feed on a variety of native plants in the absence of Eurasian watermilfoil, so the *Acentria* moth is not a typical biocontrol agent. The *Cricotopus* midge is widely distributed and has been shown to reduce the growth and biomass of Eurasian watermilfoil in laboratory experiments. This midge is not the same species of *Cricotopus* that attacks hydrilla, which suggests these insects may be host specific. It is worth noting that midges rarely feed on living plant tissue and most species typically feed on decaying organic matter. The *Eurychiopsis* weevil is generally considered to be the most important biocontrol agent of Eurasian watermilfoil from an operational perspective even though it is a native insect because this weevil prefers Eurasian watermilfoil over its native natural host. The life cycle of the weevil is completed in about 30 days; adults feed on leaves and stems, whereas larvae are stem borers that consume apical meristems. Feeding damage causes the stems to break apart and heavy feeding by the insects prevents the formation of surface mats. High populations of the *Eurychiopsis* weevil have been associated with declines of populations of Eurasian watermilfoil in some northeastern and midwestern states but fish predation may prevent this weevil from reaching its full biocontrol potential. The *Eurychiopsis* weevil is commercially available and can be purchased to augment existing weevil populations. However, research studying the value of augmenting existing populations with purchased insects has been inconclusive.

Waterlettuce – Chapter 15.8

(see http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm for more information)

Enemy	Type	Origin (date)	Success	Comments
Spodoptera pectinicornis	Moth	Thailand (1990)	Not Established	May be affected by predation by other insects
Neohydronomus affinis	Weevil	Brazil (1987)	Negligible?	

Waterlettuce is a tropical species that is believed to be native to North America and was extirpated (died out) during the Ice Ages, but was reintroduced into Florida in the 16th century. It forms large floating mats similar to those of waterhyacinth in the extreme southern US and populations of waterlettuce often increase as waterhyacinth populations decline. Waterlettuce is a public health issue in Florida, where larvae of disease-causing *Mansonia* mosquitoes (Chapter 5) attach to the extensive feathery roots to obtain oxygen. Two insects have been released as biocontrol agents of waterlettuce but only the *Neohydronomus* weevil has become established.

Adults and larvae of the *Neohydronomus* weevil feed on the leaves, crown and newly emerging shoots of waterlettuce and the characteristic "shot hole" appearance of leaves indicates high weevil densities. Feeding by multiple larvae destroys the spongy leaf bases, which causes plants to lose buoyancy. The life cycle of the *Neohydronomus* weevil is completed in 3 to 4 weeks. The weevil has not contributed to long-term suppression of the plant in the US, but has provided successful biocontrol of waterlettuce in other countries. It is thought that the *Neohydronomus* weevil is heavily preyed upon by imported fire ants in Florida; if true, this provides an interesting example of an exotic invader controlling a valuable potential biocontrol agent.

Giant salvinia (Chapter 15.9)

(see http://el.erdc.usace.army.mil/aqua/APIS/apishelp.htm for more information)

Enemy	Type	Origin (date)	Success	Comments
Cyrtobagous salviniae	Weevil	Brazil? (adventive)	Negligible, Substantial	Provides good control of common salvinia in FL but not elsewhere.
Cyrtobagous salviniae	Weevil	Brazil (2001)	Substantial?	Effects of 2001 introduction on giant salvinia are still being evaluated

The *Cyrtobagous* weevil is the only insect that has been released as a biocontrol agent of giant salvinia. Adventive weevils that were discovered in Florida in 1960 are used to control common salvinia (*Salvinia minima*), whereas weevils released in 2001 from a Brazilian population are used as biocontrol agents for giant salvinia. The entire life cycle of the *Cyrtobagous* weevil takes about 46 days. Adults feed on leaf buds and leaves and larvae tunnel inside the plant, killing leaves and rhizomes. Attacked plants turn brown and eventually lose buoyancy. *Cyrtobagous* weevils from Australia are currently of great interest to researchers and have been introduced as biocontrol agents for giant salvinia, but it is too early to determine the effectiveness of these weevils in the US.

Melaleuca (*Melaleuca quinquenerva*)

Enemy	Type	Origin (date)	Success	Comments
Oxyops vitiosa	Weevil	Australia (1997)	Substantial	Not established in permanently flooded sites due to inability to complete life cycle. Also see http://edis.ifas.ufl.edu/document_in172
Boreioglycaspis melaleucae	Psyllid	Australia (2002)	Substantial	
Fergusonina turneri	Fly	Australia (2005)	Not Established	
Lophodiplosis trifida	Fly	Australia (2008)	Negligible	Establishment confirmed http://tame.ifas.ufl.edu/photo_gallery/biocontrol/stem-gall-fly.shtml

Melaleuca is a locally invasive plant that occurs only in south Florida and the Everglades and was introduced multiple times during the early 1900s. The species was used as an ornamental tree and was planted in marshes to drain wetlands. Melaleuca typically grows in dense, impenetrable stands and can attain a height over 50 feet. Four insects have been released as biocontrol agents of melaleuca but only three have become established.

The *Oxyops* weevil and the *Boreioglycaspis* psyllid were released in 1997 and 2002, respectively, and are widely established on melaleuca in south Florida. Damage to the tree is caused primarily by the immature stages of these insects. The slug-like weevil larvae feed on newly expanding leaves; psyllid nymphs attack older leaves and woody stems in addition to new leaves and the psyllid can kill newly emerged seedlings as well. These two insects complement each other well; the psyllid is able to complete its development entirely in the tree canopy under flooded conditions that prevent establishment of the weevil, which must pupate in the soil. Extensive leaf damage from both insects causes melaleuca to divert resources to the production of new foliage instead of flowers. The life cycle of the weevil is completed in about 3 months, whereas a new psyllid generation is produced in 6 weeks. The *Oxyops* weevil and the *Boreioglycaspis* psyllid have contributed to the substantial biocontrol of melaleuca. The *Lophodiplosis* gall-forming fly was released in 2008 and has apparently become established; however, it is too early to assess its impact on melaleuca.

Summary

The use of insects as biological control agents for aquatic weeds has yielded mixed results, which is typical and expected of biocontrol programs. A number of aquatic weeds – including alligatorweed, purple loosestrife and melaleuca – are being successfully controlled by insects released as biocontrol agents for these species. Control of other aquatic weeds – including waterhyacinth, hydrilla, Eurasian watermilfoil, waterlettuce and giant salvinia – has been less successful. Multiple factors play a role in the failure of some biocontrol agents to reach their full potential. For example, the *Neohydronomus* weevil has provided successful biocontrol of waterlettuce in other countries, but has failed to control waterlettuce in Florida, possibly due to predation of the weevil by imported fire ants. Biocontrol can be an effective tool in the aquatic weed manager's arsenal since host-specific biocontrol agents allow management of populations of weedy species while leaving nontarget native plants unharmed. Therefore, it is important that researchers continue to identify and evaluate biocontrol agents so that the successes realized in the control of alligatorweed, purple loosestrife and melaleuca can be duplicated in other weedy aquatic species. A major factor that limits the utility of biocontrol is that unless a potential biocontrol agent is species-specific, it cannot be introduced into the US. Therefore, it is unlikely that biocontrol alone can control all the invasive aquatic weeds in the US.

For more information:

•Harley KLS and IW Forno. 1992. Biological control of weeds: a handbook for practitioners and students. Inkata Press, Melbourne, Australia.

Photo and illustration credits:

Page 59: Alligatorweed flea beetle; Gary Buckingham, USDA-ARS
Page 60: Graph; from Harley and Forno, 1992

Chapter 10: Grass Carp for Biocontrol of Aquatic Weeds

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Introduction

The grass carp or white amur is native to the large river systems of Eastern Asia (China, Siberia) and has been distributed worldwide for use as a food fish and for biological control of aquatic weeds. Natural reproduction of this fish is limited on a world-wide basis due to river modification and reservoir construction, but grass carp are easily produced in aquaculture using artificial means. The fish is a member of the large minnow or Cyprinid family, which includes other fish such as common carp, goldfish and our native minnows and shiners. The grass carp is very different from the well-known common carp, which is also nonnative. Several adaptations equip the grass carp for feeding on plants. For example, the mouth of the grass carp is located high on the head, whereas the mouth on the common carp is positioned low on the head to facilitate bottom feeding in shallow water, which increases turbidity. Also, the grass carp has specialized grinding teeth, which allows it to feed on aquatic plants. Juvenile grass carp consume small invertebrates but become strict vegetarians once they grow to greater than two inches in length. Grass carp are long-lived freshwater fish that can survive for up to twenty-five years if adequate food is available and can grow as much as ten pounds per year. An Arkansas angler caught a grass carp in 2004 that was 53 inches long and weighed 80 pounds. Grass carp can tolerate salinities up to 10 parts per thousand (about 1/3 the salinity of seawater), which allows the species to move through or live in the brackish waters of coastal marshes and estuaries.

History in the US

Grass carp were originally imported into the US in 1963 through a cooperative effort between Auburn University and the United States Fish and Wildlife Service. The species was imported to the US to be evaluated for its potential as a biological control agent for aquatic weeds. Grass carp have been so effective at aquatic weed control that they are now used in 35 different states, primarily for weed control in aquaculture and in closed public or private water bodies. Grass carp that escaped from early stocking programs have formed naturally reproducing populations in the Trinity River system in Texas and throughout the entire Mississippi river drainage system. Most states currently require that only artificially produced sterile triploid grass carp be stocked to prevent further natural reproduction in our remaining river systems. Triploid grass carp are created by shocking fertilized grass carp eggs with cold, heat or pressure, which renders individuals sterile and eliminates any possibility of reproduction. The use of grass carp for aquatic weed control is governed by individual states; some require permits, site inspections and use of sterile fish, whereas others have no restrictions. Many states in the northern US actually prohibit the possession, sale or transportation of grass carp. As a result, you must consult the appropriate state agencies before considering grass carp for weed control to determine whether their use is restricted or prohibited in your state.

Consumption rates and aquatic plant preferences

Grass carp consumption rates (measured as the daily percentage of body weight eaten) are affected by size of the fish and by environmental characteristics such as temperature, salinity and oxygen content of the water. Also, grass carp consumption rates decrease as fish become larger and reach sexual maturity (which occurs even in sterile fish) at 2 or 3 years of age. Large grass carp (over 15 pounds) consume up to 30% of their body weight daily, whereas smaller fish (less than 10 pounds) can consume as much as 150% of their body weight a day. Maximum consumption occurs when water temperatures range from 78 and 90 °F and is greatly reduced at temperatures below 55 degrees. Consumption is reduced by 45% when oxygen levels in the water drop to 4 ppm and fish stop feeding completely if the oxygen level drops below 2 ppm. Although grass carp can tolerate salinities up to 10 parts per thousand, they will not feed if salinity levels are higher than 6 parts per thousand.

Grass carp are general herbivores and will eat almost any plant material, including grass clippings, young waterlilies and even cattail shoots. The species does, however, have preferences for some plants, including southern naiad, hydrilla (Chapter 15.1) and duckweed (Chapter 15.10). Although grass carp do show preferences for certain plant species, they are vegetarians and will consume almost all other submersed aquatic vegetation once populations of their preferred species have been depleted. Eurasian watermilfoil (Chapter 15.2) is, however, an exception to this rule. Grass carp stocked in Deerpoint Reservoir in Florida have controlled all the hydrilla in the reservoir, but populations of Eurasian watermilfoil have increased following hydrilla removal. Grass carp are poor biocontrol agents of filamentous algae (Chapter 13), spatterdock, fragrant waterlily, sawgrass, cattail and other large plants.

Variables that affect stocking rates and duration of aquatic plant elimination

Grass carp should not be stocked in open systems that are connected to a stream or river because they migrate with moving water and will leave the stocked water body. Grass carp stocking rates in closed systems typically range from 2 to 50 fish per acre; the price of triploid grass carp ranges from 10 to $20 per fish and is dependent on proximity to the producer, the distance the fish must be transported and the size of fish desired. Most biologists agree that there is no "magic number" of grass carp to stock to achieve a specific percentage of submersed weed control because optimum stocking rate is dependent upon the type and quantity of aquatic plants present, water temperature, oxygen content and desired speed of weed control. Once grass carp are stocked, predation by fish-eating predators can be a problem because grass carp typically feed near the water surface and are commonly preyed upon by osprey, otters and other fish. For example, studies in research ponds in Florida revealed that the number of grass carp lost to predation ranged from 7 to 70% one year after stocking. Predation can be especially problematic in water bodies with large fish predators such as striped bass or largemouth bass. Grass carp that are larger than 12 inches should be used in these systems to avoid losing the majority of the stocked grass carp to predation and to ensure adequate aquatic weed control. Overstocking or excellent survival of grass carp results in removal of almost all submersed aquatic plants, whereas understocking or excessive mortality of grass carp results in no noticeable plant control. The proper balance of grass carp and weed growth is difficult to achieve and varies among waterbodies.

Complete elimination of aquatic plants by grass carp can be maintained for as long as fifteen years in the southern and the southwestern US if enough fish are initially stocked to consume the aquatic vegetation in the system, whereas control can last for up to 10 years in the rest of the country. It is important to remember that the use of grass carp as biocontrol agents is a long-term strategy because grass carp grow to an extremely large size, live up to 25 years and cannot easily be removed from a water body once they are stocked. In fact, it is not possible to remove significant numbers of grass carp from large lakes in a timely fashion. For example, significant numbers of grass carp have been removed by bow fishermen in Caney Lake in Louisiana but only after several years of effort.

Effects on water quality and fish populations

Total elimination of aquatic vegetation by grass carp usually results in changes in water quality because the water body shifts from a plant-based community to a system dominated by phytoplankton and/or algae (Chapter 1). Long-term increases in chlorophyll, total phosphorus and nitrogen often accompany the shift to a phytoplankton-based system once grass carp consume all the aquatic vegetation. In addition, water clarity usually decreases due to the increase in algae and/or phytoplankton and to wind and wave action that stirs up and suspends bare sediments.

Populations of fish species that require aquatic plants for spawning, nursery areas or as a feeding source will likely experience rapid declines or may be eliminated from the system altogether (Chapter 2). Grass carp eliminated all aquatic vegetation for 15 years in two Florida lakes, which caused the total loss of all populations of pickerel, taillight shiner, golden topminnow, bluespotted sunfish and Everglades pygmy sunfish. Both lakes also had large declines in lake chubsucker, golden shiners and warmouth

populations. In contrast, tremendous increases were noted in populations of both gizzard shad and threadfin shad after plant removal because these species feed on phytoplankton. Largemouth bass, bluegill and redear sunfish populations were not affected by elimination of all aquatic plants during this time period.

Summary

Grass carp can be an effective, cost-efficient tool for long-term aquatic plant removal in closed systems. One of the initial concerns regarding the use of this fish as a biocontrol agent in the US was the potential of escaped fish to reproduce in the wild because diploid fish have escaped into several river systems and natural reproduction has been documented in the Mississippi and Trinity River watersheds. However, the development and aquaculture production of sterile triploid grass carp has provided a solution to this problem. Grass carp remain illegal in many states and most other states require permits for use of the fish. In states where their use is allowed, utilization of grass carp as a biocontrol agent for aquatic weed management can be a very effective strategy provided decade-long control is desired and users accept that there is no way to efficiently remove the fish once they are stocked in the system.

For more information:

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- Triploid grass carp in New York ponds. New York Department of Environmental Conservation. http://www.dec.ny.gov/outdoor/7973.html

Photo and illustration credits:

Page 67: Mature grass carp; William Haller, University of Florida Center for Aquatic and Invasive Plants
Page 68: Releasing grass carp; William Haller, University of Florida Center for Aquatic and Invasive Plants
Page 69: Grass carp; Paul Shafland, Florida Fish and Wildlife Conservation Commission

Chapter 11: Chemical Control of Aquatic Weeds

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Introduction

Chemical control – the use of registered aquatic herbicides and algicides – is a technique that is widely employed by aquatic plant managers in both private and public water bodies throughout the United States. Treatments can range in size from backpack spray applications for individual plants or small clusters of plants up to large-scale treatments from boats or helicopters that may target an invasive weed throughout an entire lake. In addition, the objective of some treatments is broad spectrum control of numerous plant species, while most treatments target a specific invasive plant or algal species. The difference in scale, scope, timing, regulations and management objectives associated with the use of aquatic herbicides makes it a challenge to write an all-encompassing single chapter. In this document we seek to explain some of the rules and regulations associated with aquatic herbicide labeling, explain trade, chemical and common names, describe key differences between submersed and emergent applications, contrast contact and systemic herbicides, and provide specific information on each registered aquatic herbicide.

All herbicides discussed in this chapter have undergone EPA review (Appendix A) and have been approved for aquatic use. This does not mean these herbicides are registered or can be used in every state since most states have their own regulatory and registration procedures. In addition, some states require applicators of aquatic herbicides to be certified and licensed before these products can be purchased and used. Many states also require that permits be obtained before herbicides can be applied to bodies of water – even if the waters are privately owned. Herbicide labels and SDS (safety data sheets) are available online on the registrant's website and are excellent sources of information. ***Always read the label on the herbicide and check with the appropriate regulatory agencies in your state before purchasing or applying pesticides to any body of water***.

Like all pesticides, aquatic herbicides have three names: a trade name, a common name and a chemical name. The trade name of a product is trademarked and is owned by the company, whereas the common name and the chemical name are assigned by the American National Standards Institute and the rules of organic chemistry, respectively. For example, consider the aquatic herbicide Rodeo®. The trade name of this herbicide is Rodeo®, the common name is glyphosate and the chemical name is N-(phosphono-methyl) glycine, isopropylamine salt. If a particular pesticide is protected by a patent, there may be only a single trade name associated with that pesticide. However, if the pesticide is off-patent, there may be multiple trade names that share the same common and chemical name. A number of aquatic herbicides are off-patent and have multiple trade names; therefore, we refer to herbicides by their common names only throughout most of this handbook.

There are approximately 300 herbicides registered in the US, but only 14 are currently registered for use in aquatic systems. Herbicide labels often include a list of the nuisance species controlled by the product, but applicators may be allowed to use the herbicide to control a target weed not listed on the herbicide label provided the product is labeled for use at the desired site of application. For example, if you wish to use an herbicide to control a weed in your pond and the weed is not listed on the herbicide label, you may still be able to use the product to control this particular weed if the label specifies that the herbicide may be used in ponds. However, it is important to check with state authorities before doing so because some states specify that herbicides can only be used to control weeds that are listed on the product label. Additionally, the user accepts liability for the performance of the product if the specific weed is not included on the label.

Herbicides can be classified in several ways, including by their chemical family, their mode of action (how they work) and their time of application in relation to growth of the weed. In this handbook we will classify aquatic herbicides based upon how they are applied (as foliar or submersed treatments – although some herbicides are both) and on their activity in the plant (systemic or contact).

Products that are applied as foliar treatments are most easily recognized by the public. For example, if you have a weed to control, you select a herbicide based on label directions, mix the product with the prescribed amount of water and apply it directly to the weed. Contact products work quickly and kill the plant rapidly on contact (hence the designation "contact"). Systemic compounds, on the other hand, usually work slowly by affecting biochemical pathways and must be absorbed by the plant before providing control; therefore, systemic compounds may require days or weeks to kill the weed. The application method is the same for both systemic and contact herbicides – the compound is applied directly to the foliage of the plant. Foliar herbicides are used to control floating, floating-leaved and emergent aquatic weeds.

Submersed herbicides are applied as concentrated liquids, granules or pellets. Liquid treatments are often mixed with water to facilitate application and to ensure even distribution and are applied to achieve an entire water volume concentration to control submersed weeds and planktonic algae. Some dry formulations (wettable powders, water dispersible granules) are mixed with water and applied similar to liquids, but many granular and pelleted products are applied using granular spreaders. Aquatic herbicide applicators must determine the volume of the water to be treated before applying submersed herbicides to ensure that the appropriate and effective amount of herbicide is used. The following constants are needed to calculate the volume of water before treatment with submersed herbicides:

- The volume of a body of water is calculated in acre-feet, which is a function of area and depth; for example, a lake with an area of 1 acre and a depth of 6 feet has a volume of 6 acre-feet
- A single acre-foot of water comprises around 326,000 gallons of water and weighs around 2.7 million pounds

The volume (in acre-feet) of a body of water or treatment site is used to determine the amount of herbicide needed to control a particular weed. For example, if the label of a herbicide specifies an application rate of 1 ppm (part per million), then 2.7 pounds of the herbicide's active ingredient must be applied for each acre-foot of the water to effectively control the target weed. This results in a concentration of 1 ppm since 2.7 pounds of herbicide are mixed with 2.7 million pounds of water in each acre-foot. Most herbicide labels include a table that lists application rates, but it may be necessary to perform calculations similar to those described above to ensure that the correct dosage of herbicide is applied. The labels of aquatic herbicides clearly state how these calculations are performed.

Contact Herbicides

Several herbicides registered for aquatic use are classified as contact herbicides. This term may lead one to believe that these herbicides kill weeds immediately after contacting them. While contact herbicides tend to result in rapid injury and death of the contacted plant tissues, it is important to realize that the term “contact herbicide” refers to the lack of translocation or mobility of the herbicide in the plant after the herbicide is taken into the plant tissue. Herbicides that are able to move through plant tissues following uptake are said to translocate; these products are called “systemic herbicides.” This distinction between contact and systemic herbicides has significant implications for the prescribed use of the products and usually describes how quickly weeds may be controlled.

Contact herbicides are often used for foliar treatment of sensitive free-floating plants such as waterlettuce (Chapter 15.8), duckweed (Chapter 15.10) and salvinia (Chapter 15.9) and good spray coverage is essential to ensure control of all individual plants of these species. Contact herbicides are also used to temporarily control a number of emergent aquatic plants. These treatments are often initially effective, but treating emergent plants with a contact herbicide often results in rapid recovery and significant regrowth from plant tissues that do not come into contact with the herbicide. As a result, systemic products are usually preferred for controlling emergent plants because systemic herbicides move or translocate within the plant and kill underground roots and rhizomes, which reduces or eliminates regrowth.

Contact herbicides that are used to control submersed weeds must remain in the water within the treated area for a few hours to a few days so that plants are exposed to a lethal concentration of the herbicide for a sufficient amount of time. The results of a herbicide application designed to control submersed plants is primarily impacted by two key factors:

1) the concentration of the herbicide in water that surrounds the target plant
2) the length of time a target plant is exposed to dissipating concentrations of that herbicide

This dose/response phenomenon is herbicide- and plant-specific and has been defined as a concentration and exposure time (CET) relationship. Contact herbicides have relatively short exposure time requirements (often measured in hours or days), which means that these products are used to target specific areas within a larger water body or in areas where significant dilution is expected. Whether for contact or systemic herbicides, the vast majority of poor treatment results following submersed applications are due to an inability to maintain the herbicide in contact with the target plants at a lethal concentration for an appropriate period of time. Each contact herbicide has a different use rate, exposure requirement and selectivity spectrum. While the registered contact herbicides are often referred to as “broad-spectrum” products, there is a range of plant susceptibilities to each of these contact herbicides based on the species, use rate, treatment timing and exposure period. Proper identification of target and nontarget plants is important when selecting a contact product because herbicides can significantly differ in their selectivity to various plant species.

Susceptible submersed plants that are treated with contact herbicides typically show symptoms of herbicide damage within a day or two of treatment and collapse of the target plants can occur within 3 to 14 days. It is important to note that the use of contact herbicides in areas with dense plant populations and warm water temperatures can lead to a situation where decomposing plant tissue quickly depletes the oxygen from the water column, resulting in conditions that can cause a fish kill. Product labels have directions that provide guidance to avoid oxygen depletion when treatments are made under conditions of dense vegetative cover and warmer water temperatures.

Compound/ Date registered for aquatic use	Primary use			Formulation	Mode of Action	Comments
	Submersed	Floating	Emergent			
Copper 1950s	X	X		Liquid chelates Granular $CuSO_4$ Granular chelates	Contact Plant cell toxicant	Algae control Also used in combination with other herbicides Often used for submersed plants near potable water intakes Typical use rates: 0.2 to 1 ppm
Endothall 1960	X	X		Liquid Granular	Contact Inhibits respiration and protein synthesis	Dipotassium salt for submersed plant control Use in irrigation canals (2010) Dimethyl-alkylamine salt for algae and plants that are more herbicide-tolerant Treatment timing affects selectivity Typical use rates: 0.3 to 3 ppm (submersed)
Diquat 1962	X	X	X	Liquid	Contact Inhibits photosynthesis and destroys cell membranes	Broad spectrum Turbidity affects effectiveness Very fast activity on sensitive plants; faster activity under high light conditions Typical use rates 0.1 to 0.37 ppm
Peroxides 1980s		X		Liquid Granular	Contact Affects cell wall permeability, cell membrane integrity	Algae control, particularly certain species of floating filamentous algae
Carfentrazone 2004	X	X	X	Liquid	Contact Inhibits plant-specific enzyme (PPO); causes rapid desiccation and necrosis	Waterlettuce and broadleaf weed control Activity on select submersed species pH of the water can impact efficacy Typical submersed use rates – 50 to 200 ppb
Flumioxazin 2011	X	X	X	Water dispersible granule	Contact Inhibits plant-specific enzyme (PPO); causes rapid desiccation and necrosis	Waterlettuce, surface sprays for algae control, submersed plant control pH of the water can impact efficacy Typical submersed use rates – 50 to 200 ppb Mixed with glyphosate for emergent plants

It is important that contact herbicides be applied and distributed as evenly as possible to the target plant (or throughout the water column for control of submersed plants) to ensure that the entire plant – including the rooted portions of the plant near the sediment – is exposed to the herbicide. Poor mixing of contact herbicides within the water column can result in control of plant tissue growing near the water surface, followed by rapid recovery from the lower portions of the plant that were not exposed to the herbicide. Poor control can also result from summer applications when treating lakes that are thermally stratified (Appendix B).

Contact herbicides are currently used for both small-scale treatments such as along shorelines and for large-scale control efforts. Most of the contact herbicides have been registered for many decades and they tend to be versatile with a wide range of use patterns. Combinations of two or more contact herbicides are often used to target specific invasive or nuisance species. The registered contact herbicides (and dates of registration) are described in more detail below. These brief descriptions are not comprehensive, but are meant to serve as a guide to particular historical strengths or potential issues associated with the use of these products.

Copper (1950s)

Copper is a micronutrient that is needed for healthy growth of animals and is often added to animal feed and to vitamins formulated for human use. Copper is widely used as a fungicide in agricultural systems to control diseases on food crops and copper-based compounds have been used for aquatic plant control since the early 1900s. Copper sulfate is likely the most widely used copper product, but it is corrosive and its effectiveness can be affected by water hardness. Liquid chelated copper compounds were developed in the 1970s to address these problems. Copper compounds are used primarily to control algae and plants growing in irrigation canals, ponds, lakes and reservoirs. Submersed use rates typically range from 0.2 to 1.0 mg/L copper in the water column. There are no restrictions on the use of copper in potable water sources or in waters used for crop irrigation. This allows the immediate use of treated water and helps to explain why copper is widely used to control nuisance plants in drinking water supplies and irrigation canals. Copper acts very quickly on plants and algae and has a short exposure requirement, which can be advantageous when treating small areas or areas subject to rapid dilution. The effectiveness of copper as a herbicide or algicide can be affected by alkalinity or hardness of the water. For example, high alkalinity or hard water can reduce the effectiveness of copper-based products. Despite these limitations, copper remains the major tool for algae control in potable water systems, irrigation canals and in small water bodies. Copper does not biodegrade and regular use can result in increased copper residues in the sediment. Copper is generally considered to be biologically inactive once bound in the sediments.

Endothall (1960)

Endothall is used primarily to control submersed plants and use rates and methods of application vary widely. Traditional use patterns of endothall have included spot treatments of small target areas in which treatments are generally applied at the highest label rate and species selectivity is not a major concern. Selective use of the product is based on species sensitivity, use rates and treatment timing. The effectiveness of endothall is generally not affected by factors such as alkalinity or turbidity of the water. Within the last several years, large-scale early-season treatments have been applied to target invasive plants such as hydrilla (Chapter 15.1), curlyleaf pondweed (Chapter 15.3) and Eurasian watermilfoil (Chapter 15.2) that persist throughout the winter. These treatments are conducted before desirable native plants begin to grow in spring, which may allow control of the invasive weeds with limited impact on native species that grow later in the season. It is important to note that these early-season treatments are applied when plant biomass is not at its peak and when water temperatures are cooler. These conditions reduce or prevent oxygen depletion that may occur when fast-acting contact herbicides are applied to dense nuisance populations of weeds in warmer water. Endothall is also widely used in control of submersed weeds and algae in irrigation canals. Endothall has also been used to control weeds in turf and to desiccate cotton and potato plants to aid in harvesting.

Diquat (1962)

Diquat is a fast-acting contact herbicide that interferes with photosynthesis in susceptible plant species. Diquat effectively controls many free-floating weeds including duckweed, watermeal, waterlettuce and salvinia. As noted above, good coverage is critical when treating these plants because missing a small area or a few individuals can lead to rapid recolonization by these fast-growing floating species. Diquat is also used to control submersed plants in small treatment areas or in areas where dilution may reduce the period of time that plants are exposed to the herbicide. Diquat is generally considered to be a "broad-spectrum" product that kills a wide range of plant species. However, the susceptibility of different submersed species can vary significantly. Diquat can be rapidly inactivated when treating "muddy" or turbid water and the speed of this inactivation can interfere with plant control. There are no hard and fast rules to determine when water is too muddy to treat, but the effectiveness of diquat increases as water clarity increases. Diquat is often mixed with copper-based herbicides to control a broader range of weeds and to improve control of target plants. In addition to its use in aquatic systems, diquat is labeled for weed control in turf and along fence lines and has been used to kill the leaves and vines of potato to increase ease of harvesting.

Peroxides (1980s)

Several inorganic chemicals produce peroxide (principally hydrogen peroxide) when mixed with water. This contact algicide is used in aquatic systems mainly for control of algae with very limited use for control of submersed vascular plants. Blowers or granular spreaders are used to ensure uniform coverage of the water surface. These compounds produce hydrogen peroxide – which is toxic to some species of algae – when they come into contact with water. Hydrogen peroxide then rapidly breaks down into water, oxygen and other natural products. It is recommended that treatments be applied on sunny days when algal densities remain low. Often used to control algae in potable water supplies, hydrogen peroxide is also widely used in the medical field to kill bacteria.

Carfentrazone (2004)

Carfentrazone affects a plant-specific enzyme (protoporphyrinogen oxidase); however, the rapid onset of symptoms (membrane destruction, tissue necrosis) is similar to contact herbicides. In contrast to the registered contact herbicides mentioned above, carfentrazone has a much more narrow spectrum of weed control. While this can limit the utility of the product to a few target weeds, it can also result in improved selectivity and reduced damage to nontarget plants. To date, carfentrazone has been used for control of waterlettuce, duckweed and in combination with other herbicides for selective control of some broadleaf emergent plants. Carfentrazone is also labeled for submersed plant control; however, limited use of carfentrazone to date has hampered the development of new use patterns for this product and more research is needed before it will be widely used on submersed weeds. Managers have noted that carfentrazone performance improves when applications are made on sunny days, but high water pH may reduce carfentrazone activity on submersed plants due to rapid hydrolysis of the herbicide. Carfentrazone is also used for weed control in turf, corn and other crops.

Flumioxazin (2011)

Flumioxazin has the same mode of action as carfentrazone and the onset of rapid injury is similar to other contact herbicides, but flumioxazin has a broader spectrum of activity compared to carfentrazone. Flumioxazin has only been registered for a short period of time, so use patterns are still being developed. Current uses include control of floating plants such as waterlettuce, duckweed and watermeal, surface mats of filamentous algae (Chapter 13), submersed species such as fanwort (Chapter 15.5), and to enhance control of emergent weeds when used in combination with glyphosate and auxin mimic herbicides. Field use has shown that surface and submersed applications of flumioxazin provide good control of spatterdock (*Nuphar* sp.), waterlily (*Nymphaea* sp.) and American lotus (*Nelumbo lutea*). Water pH significantly affects the activity of this herbicide, particularly in submersed treatments, because flumioxazin degrades very rapidly when water pH is 8 or above, but the role of pH on efficacy of flumioxazin in submersed applications is still being evaluated. Flumioxazin is also widely used in agronomic crops.

Systemic herbicides – auxin mimics

In contrast to contact herbicides, systemic herbicides are mobile in plant tissue and move through the plant's water-conducting system (xylem) or food-transporting vessels (phloem). Once the herbicide is absorbed into the plant, it can move through one or both of these vessels and throughout the plant tissue to affect all portions of the plant, including underground roots and rhizomes. Auxin mimic herbicides simulate auxin, a naturally occurring plant hormone that regulates plant growth. These herbicides generally target broadleaf plants (dicotyledons or dicots) and are often called "selective herbicides" because many aquatic species (particularly grasses or monocots) are not susceptible to auxin mimic herbicides. In fact, the majority of submersed aquatic plants are monocots, which aids in selectivity when using an auxin mimic. After treatment, the shoot tissue of susceptible plants will often bend and twist (epinasty) and plants will often collapse 2 to 3 weeks after herbicide application. Similar to contact herbicides, auxin mimics that are used to control submersed weeds must remain in the treated area for a few hours to a few days so that plants are exposed to a lethal concentration of the herbicide for a sufficient amount of time. Longer exposure periods (such as 24 to 144 hours) increase the probability that the target weed will be completely controlled, but exposure times of 12 hours or greater may provide good control, provided the application rate and timing are appropriate. The contact herbicides discussed above are used to control a large number of nuisance and invasive plant species, but auxin mimic herbicides are used for control of a much smaller number of plant species.

While there are several aquatic dicotyledons (and some monocots) that show sensitivity to the auxin mimics, these herbicides have historically been used for selective control of a limited number of emergent, floating and submersed plants, including waterhyacinth (Chapter 15.7) and Eurasian watermilfoil. The auxin mimics 2,4–D and triclopyr have very similar use patterns and are used to control broadleaf plants growing among desirable grasses or native submersed plants. This is referred to as "selective control" and is very important in aquatic sites to maintain native species while reducing growth of invasive weeds. These herbicides are also widely used to control weeds in turf, pastures, forestry and other terrestrial sites.

Compound/ Date registered for aquatic use	Primary use			Formulation	Mode of action	Comments
	Submersed	Floating	Emergent			
2,4-D 1959 (granular) 1976 (liquid)	X	X	X	Granular ester Granular amine Liquid amine	Systemic Auxin mimic, plant growth regulator	Used for submersed dicots such as Eurasian watermilfoil and for waterhyacinth management Typical use rates: 0.5 to 4 ppm (submersed); 2 to 4 pounds per acre (foliar)
Triclopyr 2002	X	X	X	Liquid Granular	Systemic Auxin mimic, plant growth regulator	Used for submersed dicots such as Eurasian watermilfoil; also for floating and emergent plants Typical use rates: 0.25 to 2.5 ppm (submersed); 1 to 3 pounds per acre (foliar)

2,4–D (1959)

Several nuisance emergent and submersed plants are controlled by 2,4–D, but this herbicide is primarily used for selective control of waterhyacinth and Eurasian watermilfoil. A liquid amine formulation is used to control emergent and submersed plants and a granular ester formulation is used for submersed weed control. In addition, a granular amine formulation has been recently registered. Some native emergent plants – including waterlilies, spatterdock and bulrush – are susceptible to 2,4–D, so care should be taken to avoid injury to these plants. 2,4–D has been used for more than 50 years to control broadleaf weeds in pastures, crops, turf and aquatic systems.

Triclopyr (2002)

Triclopyr was registered for aquatic use in 2002 and to date the major use of his herbicide has been for selective control of Eurasian watermilfoil. Similar to 2,4–D, there are certainly other plant species that are susceptible to triclopyr; however, the historical strength of auxin mimic herbicides has been selective control of invasives such as Eurasian watermilfoil or waterhyacinth. Triclopyr is registered as both liquid and granular amine formulations. Like 2,4–D, some native non-target emergent plants are susceptible to triclopyr, so care should be taken to avoid injury to these plants. The use of triclopyr in public waters is permitted in some states where 2,4–D use is not allowed. Triclopyr is also labeled for control of broadleaf weeds in turf, forestry and crop production.

Systemic herbicides – enzyme specific herbicides for foliar use

Two aquatic herbicides – glyphosate and imazapyr – are labeled only for foliar treatment and control of emergent and floating plants. Both are systemic and readily move through plant tissue to control aboveground and underground portions of the plant. These herbicides inhibit enzymes that plants need to produce proteins that are required for growth, so plants treated with these systemic herbicides slowly “starve” and eventually die. These herbicides target enzymes in a pathway that is found only in plants. Herbicides that target plant-specific enzymes typically show very low toxicity to non-plant organisms such as mammals, fish and invertebrates. Both of these herbicides are truly broad-spectrum and a very limited number of emergent plant species can tolerate exposure to them. These herbicides are especially effective at controlling large monotypic stands of nuisance emergent plants such as phragmites (Chapter 15.11), cattail and other invasive perennial plants that have extensive rhizome and root systems. Both products result in fairly slow control of target weeds and are often mixed together for plants that are particularly hard to control.

Compound/ Date registered for aquatic use	Primary use			Formulation	Mode of action	Comments
	Submersed	Floating	Emergent			
Glyphosate 1977			X	Liquid	Systemic Inhibits plant-specific enzyme (EPSP) New growth stunted	Broad spectrum for emergent plant control Plant death may be slow Not active in soil
Imazapyr 2003			X	Liquid	Systemic Inhibits plant specific enzyme (ALS)	Broad-spectrum for emergent plant control Plant death may be slow Active in soil – cannot be used in irrigation ditches

Glyphosate (1977)

Glyphosate is widely used in agriculture, homeowner and specialty markets, including aquatics. Glyphosate is translocated through treated plant tissues; new growth is disrupted and plants die 1 to 4 weeks after herbicide application. Glyphosate has no soil activity and is rapidly deactivated in natural waters via binding to various cations in the water and therefore it cannot be used for control of submersed weeds. Because this herbicide is rendered inactive so quickly, the irrigation or potable water restrictions associated with the use of glyphosate are minimal. Treatment timing can impact the effectiveness of glyphosate and nuisance species should be treated during late summer or fall when plants are moving sugars to storage organs such as roots or rhizomes in preparation for overwintering. This treatment timing can increase the translocation of glyphosate into the storage organs and often results in enhanced control of the target plant during the following growing season.

Imazapyr (2003)

Imazapyr is also used in forestry and specialty markets, including aquatics, where it was registered for control of aquatic weeds in 2003. Imazapyr inhibits the plant-specific enzyme acetolactate synthase (ALS), which plays a critical role in protein production in plants. This herbicide has been used to control invasive plants such as spartina or phragmites that have invaded previously unvegetated areas in tidal zones or river flats. Similar to glyphosate, imazapyr readily translocates throughout the plant and new growth is inhibited due to the lack of protein production. Imazapyr should be applied when the plants are actively growing in the spring, summer or fall and is absorbed through plant leaves and roots. Unlike glyphosate, imazapyr is active in the soil so care should be taken to avoid treating areas around the root zones of desirable plants, particularly near trees along the water's edge.

Systemic bleaching herbicides

Compound/ Date Registered for aquatic use	Primary use			Formulation	Mode of action	Comments
	Submersed	Floating	Emergent			
Fluridone 1986	X	X		Liquid Granular	Systemic Inhibits plant-specific enzyme (PDS) New shoot growth is bleached	Large-scale or whole-lake management Low use rates, long exposure requirements Treatment timing and use rate affects selectivity Used for some floating plants Typical use rates: 5 to 30 ppb (submersed)
Topramezone 2013	X	X		Liquid	Systemic Inhibits plant-specific enzyme (HPPD) New shoot growth is bleached	Large-scale or whole-lake management Low use rates, long exposure requirements Treatment timing and use rate affects selectivity Used for some floating plants Typical use rates: 20 to 40 ppb (submersed)

Fluridone (1986)

Fluridone is a bleaching herbicide that targets a plant-specific enzyme (phytoene desaturase) that protects chlorophyll, the green pigment responsible for photosynthesis in plants. Fluridone is used primarily to control submersed [e.g., Eurasian watermilfoil, hydrilla and egeria (Chapter 15.4)] and floating plants (e.g., duckweed, watermeal and salvinia) by treating the water column. Fluridone symptoms are highly visible, with the new growth of sensitive plants bleaching or turning white as chlorophyll in the plant is destroyed by sunlight. Susceptible plants will show bleaching symptoms in new shoot growth; however, it is important to note that bleaching symptoms don't always equal control and actual plant death may not occur for months after an initial treatment. Fluridone can be both selective and broad-spectrum and use rates vary from 4 to 150 ug/L. Higher rates often provide broad-spectrum control, whereas lower rates increase selectivity.

Unlike the contact or auxin mimic herbicides that require hours or days of exposure, the fluridone label states that target weeds must be exposed to fluridone for a minimum of 45 days. The extended exposure requirement typically calls for treatment of the entire aquatic system or treatment of protected embayments of lakes or reservoirs. Required exposure periods will often depend on the plant species, stage of plant growth and treatment timing. During the exposure period, new shoot growth of susceptible plants becomes bleached and this continuous bleaching of new growth depletes the plant's reserves of carbohydrates needed for growth. This slow death (which may take 2 or more months) can allow plants to continue to provide structure for habitat and produce oxygen through photosynthesis. Despite the extended herbicide exposure requirements associated with fluridone treatments, there are no restrictions for potable water use, fishing or swimming; however, irrigation restrictions are described on the product label. Fluridone has been used for numerous whole-lake management treatments throughout the United States targeting invasive submersed weeds such as hydrilla and Eurasian watermilfoil.

Fluridone is available in both liquid and pellet formulations. Both products require that plants be exposed to sufficient concentrations of fluridone for an appropriate period of time. As a result, sequential fluridone treatments – often called "bumps" – are usually applied over a period of time to ensure that an effective concentration of the herbicide is maintained. Due to the long-lived nature and critical exposure time requirements, fluridone treatments are often monitored to measure fluridone concentrations in the treated water. This helps to determine if further applications are necessary to maintain a lethal concentration of the herbicide. The main degradation pathway for fluridone is via photolytic processes, or breakdown by ultraviolet wavelengths in sunlight.

Fluridone is also applied to the water column to control floating plants such as duckweed, salvinia and watermeal in small water bodies. Floating plants are generally controlled much more quickly than submersed species. Fluridone can be used in systems of less than one acre and in systems that exceed several thousand acres. Regardless of the size of the treatment, target plants must be exposed to sufficient concentrations of fluridone for an appropriate period of time in order to effectively control target plants.

Topramezone (2013)

Topramezone is a recently registered bleaching herbicide that targets a plant-specific enzyme (4-hydroxyphenyl-pyruvate dioxygenase) that protects chlorophyll, the green pigment responsible for photosynthesis in plants. Although use patterns are still being developed, it is likely that topramezone will share many of the characteristics described for fluridone. This includes: 1) low use rates (20 to 40 ppb); 2) extended exposure requirement of > 45 days; 3) rate-based selectivity; 4) bleaching of new plant growth; 5) slow death of target plants; 6) water sampling to manage long-term herbicide concentrations; 7) no use restrictions on drinking, swimming and fishing; and 8) whole-lake or large-scale use patterns. The current topramezone label includes submersed weeds such as hydrilla and Eurasian watermilfoil and floating plants such as duckweed and waterhyacinth. New use patterns will be developed for both small and large water bodies over time as resource managers become familiar with this product. The main degradation pathway for topramezone is via photolysis.

Systemic herbicides – ALS herbicides

Several recently registered herbicides include compounds that target the plant-specific enzyme acetolactate synthase (ALS). As noted above for imazapyr, this enzyme plays a key role in the production of amino acids needed for protein synthesis in plants and the affected pathway does not occur in animals. In contrast to the broad-spectrum activity described for glyphosate and imazapyr above, the newly registered ALS herbicides tend to be much more selective. Despite a similar mode of action, use patterns vary substantially among these products. Similar to other enzyme specific inhibitors, these herbicides are applied at comparatively low use rates and result in a slow kill of the target weed. Susceptible floating plants are often controlled much more quickly than large emergent rooted plants or submersed plants. Although systemic ALS herbicides do not result in bleaching of new plant growth, they are similar to the bleaching herbicides since they require 1 to 3 or more months of exposure to achieve control of submersed weeds.

Compound/ Date registered for aquatic use	Primary use			Formulation	Mode of action	Comments
	Submersed	Floating	Emergent			
Penoxsulam 2007	X	X		Liquid	Systemic Inhibits plant-specific enzyme (ALS) New growth stunted	Large-scale control of hydrilla and other submersed plants Floating plant control Extended exposure required for submersed plant control Typical use rates: 10 to 30 ppb (submersed)
Imazamox 2008	X	X	X	Liquid	Systemic Inhibits plant-specific enzyme (ALS) New growth stunted	Selective emergent plant control Waterhyacinth control Growth regulation and control in hydrilla Typical use rates: 25 to 75 ppb (submersed)
Bispyribac-sodium 2012	X	X		Wettable powder	Systemic Inhibits plant-specific enzyme (ALS) New growth stunted	Large-scale control of hydrilla and other submersed plants Floating plant control Extended exposure required for submersed plant control Typical use rates: 20 to 40 ppb (submersed)

Penoxsulam (2007)

Penoxsulam was registered for aquatic use in 2007 and is currently applied to control floating species such as waterhyacinth, waterlettuce and salvinia and submersed plants such as hydrilla. Treatments may include foliar application of penoxsulam directly to the target floating plants or submersed application for control of both submersed and floating plants. Penoxsulam use rates and exposure requirements for submersed applications are generally similar to those of fluridone and plant death may occur over a period of 60 to 100+ days depending on the plant species, stage of plant growth and treatment timing. During the exposure period, new shoot growth is inhibited and plants can turn red in color due to stress. The extended exposure requirement typically necessitates treatment of the entire aquatic system or application to protected embayments of lakes or reservoirs where dilution from water exchange is minimized. Combining penoxsulam with the contact herbicide endothall can greatly increase the speed of control and may reduce the penoxsulam exposure requirements. Despite the extended herbicide contact time associated with penoxsulam treatments, there are no restrictions on use of water for drinking, fishing or swimming, but irrigation restrictions are described on the product label. Penoxsulam is also registered for weed control in rice and turf. The main degradation pathway is via photolytic processes.

Imazamox (2008)

Imazamox was registered for aquatic use in 2008 and is currently used for selective control of large emergent species such as phragmites, Chinese tallow, cattail and wild taro, and for floating species such as waterhyacinth. Emergent and floating plant use patterns are very similar to imazapyr; however, imazamox is often used in situations where greater selectivity is desired. Use of imazamox for submersed plant control has been somewhat limited and has focused on growth suppression of hydrilla and control of curlyleaf pondweed. Selective use patterns for emergent and submersed applications of imazamox in aquatic systems are still being developed. There are no restrictions on the use of the imazamox-treated water for drinking, fishing, swimming and minimal restrictions for irrigation. Imazamox is also registered for weed control in turf and rice. The main degradation pathway for imazamox is via photolytic processes.

Bispyribac-sodium (2012)

Bispyribac-sodium was registered for aquatic use in 2012 and it is currently being applied for whole-lake and large-scale treatments of hydrilla. This product is newly registered and a number of use patterns are being evaluated, but use patterns of bispyribac-sodium are likely to be similar to those of penoxsulam. These similarities include: 1) low use rates in the 15 to 40 ppb range; 2) extended exposure requirements of 60 to 100+ days; 3) same mode of action; 4) rapid cessation of new plant growth and slow death of target plants; 5) water sampling to manage long-term herbicide concentrations; 6) no use restrictions on drinking, swimming and fishing; and 7) whole-lake or large-scale use patterns. Bispyribac-sodium is currently being evaluated in combination with flumioxazin and carfentrazone for control of waterhyacinth and other weedy species.

Herbicide resistance and resistance management

Aquatic plant management has been largely unaffected by issues related to herbicide resistance. Nonetheless, the discovery of large-scale resistance of formerly sensitive populations of hydrilla to the herbicide fluridone in Florida during 2000 and 2001 was an unexpected development that has made aquatic managers much more sensitive to this issue. The biochemical basis for resistance development is beyond the scope of this document; however, factors that are known to foster development of resistance include:

1) repeated use of the same herbicide within and over multiple seasons
2) use of herbicides that target plant-specific enzymes (e.g., ALS inhibitors)

When possible, managers should consider rotation of herbicides to reduce the potential for resistance development. In addition, if a manager observes a formerly sensitive target plant population showing a significant change in response to a herbicide, they should immediately contact an aquatic weed specialist for further evaluation of the situation.

Herbicide dissipation and half-lives

The length of time a herbicide remains in contact with target plants following a submersed application is critical to achieving desired results. The two key processes that dictate the required exposure of plants to herbicides are herbicide dispersion and degradation. Once applied to the water, herbicides are subject to dispersion or movement both within and away from the treated area. Dispersion initially has a positive influence on the treatment because it facilitates mixing of the herbicide in the water column. The rate of movement of herbicide residues from the treatment area is likely the largest single factor affecting treatment success, especially for those treatments applied to a small area in a larger water body. For example, application of a herbicide to a 10-acre protected cove in a large reservoir may result in limited movement outside of the treatment area and a subsequent long exposure period. In contrast, a 10-acre plot applied along an unprotected shoreline of the same reservoir on the same day may result in the herbicide moving out of the target area and becoming diluted to less-than-lethal concentrations within a few hours of treatment. Conditions on the day of treatment can also be very important, especially for treatments applied to unprotected areas of larger lakes. High winds or high water flow associated with recent precipitation can have a strong negative influence on treatment results. As the potential range of exposure periods can vary significantly at the same site from day to day, even greater variation between sites is likely. This variation in the expected exposure period will often influence both choice and application rate of the selected herbicide.

In addition to dispersion, herbicide degradation plays a significant role in the effectiveness of a treatment. With the exception of copper (a natural element), all herbicides are subject to degradation pathways that ultimately lead to breakdown products that include carbon, hydrogen and other simple compounds. These degradation pathways result in decomposition of the herbicide to simpler products that lack herbicidal activity via processes such as photolysis (breakdown by ultraviolet rays in sunlight), microbial degradation (breakdown via action of the microbial community) or hydrolysis (breakdown via the action of water splitting the herbicide molecule). Environmental conditions such as temperature, hours of sunlight, trophic status of the water body and pH can all influence the rate of degradation of the different herbicides. In terms of herbicidal effectiveness, degradation pathways are particularly important for products like fluridone or penoxsulam that require long exposure periods of 30 to 100 days. In these situations, the entire water body is often treated and therefore dispersion or dilution is not an issue, but the rate of degradation will often dictate product effectiveness. The role of pH for products that are degraded via hydrolysis such as flumioxazin and carfentrazone is relatively new to aquatic plant management, and managers need to consider pH as a significant factor in product performance. It is also important to mention the phenomenon of herbicide binding in relation to herbicide effectiveness. Several herbicides can bind with various ions in the water column, which can result in a reduction or loss of herbicidal activity. Binding is not a degradation pathway, but it can have an important influence on herbicide effectiveness. The best examples of product binding are the immediate binding of glyphosate to positively charged cations in the water column and the binding of diquat to negatively charged particles such as clay or organic matter in the water column. In both of these cases, the herbicide molecule remains intact but no longer has any herbicidal activity. The bound particles eventually settle to the sediments where microbial degradation takes place. Herbicides that are chemically bound in the sediment no longer have herbicidal activity and undergo microbial degradation over time.

The tables on pages 87 and 88 provide general information about exposure time requirements, typical aqueous half-lives that result from product degradation and the key degradation pathways for aquatic herbicides.

Herbicide Concentration Monitoring

The above discussion of herbicide dissipation and half-lives is relevant to current use patterns of many aquatic herbicides. Operational monitoring of herbicide concentrations has increased significantly over the past 10 years. The advent of enzyme-linked immunoassays (ELISA) for several of the registered aquatic herbicides (including fluridone, endothall, triclopyr, 2,4–D, penoxsulam and bispyribac-sodium) has largely been responsible for this trend. While monitoring used to be very costly and was associated almost exclusively with regulatory studies or field research trials, several groups now offer monitoring support for operational treatments. When managers select herbicides such as fluridone and bispyribac, the extended exposure requirements and large-scale use patterns are often supported by monitoring programs. In this case the monitoring can be used to manage the concentrations and exposure periods and to determine when and if additional herbicide applications are necessary to achieve optimal target plant control. In addition, monitoring can be used to determine when herbicide concentrations become low enough that use restrictions on water can be lifted (e.g. irrigation, potable water use). There are numerous potential uses for operational monitoring of aquatic herbicide concentrations and given the value of the information that can be obtained, it is likely this trend will increase in the future.

Summary

This chapter lists fourteen products that are registered by the EPA for aquatic plant control in aquatic systems. These herbicides are very different from one another; some have been used for decades, whereas others have only recently been approved for use in water. More specific directions regarding the use of these products are on the label and are also available from the companies that manufacture, sell or distribute these herbicides.

For more information:

•Aquatic Plant Management Society. http://www.apms.org
•University of Florida Center for Aquatic and Invasive Plants. http://plants.ifas.ufl.edu
•US Army Corps of Engineers. http://www.erdc.usace.army.mil/pls/erdcpub/docs

Contact herbicides: contact exposure requirements, half-lives and degradation pathways

Compound	General Exposure Requirements	Typical half-life in water	Key degradation pathway and comments
Copper	Hours to 1 day	Hours to 1+ day	Copper is a natural element and is therefore not subject to degradation. Following application, copper ions are typically bound to particles or chemical ions in the water or sediment, which results in the loss of biological activity. Active copper ions in the water column are more readily inactivated in hard water systems. Concerns have been expressed regarding buildup of copper residues in sediments.
Endothall	Hours to days	2 to 14+ days	Endothall is a simple acid that is degraded via microbial action. Water temperature and the level of microbial activity can have a strong influence on the rate of degradation. Cooler water temperatures typically result in slower rates of degradation.
Diquat	Hours to days	½ to 7 days	Diquat is rapidly bound to negatively charged particles in the water column. Higher turbidity water can result in very fast deactivation of the diquat molecule. The ionic bonds between diquat and charged particles negate herbicidal activity. Once biologically inactivated, diquat is then slowly degraded via microbial action.
Peroxides	Minutes to hours	Rapid	Peroxide based algaecides are short lived in the water column and quickly breakdown via abiotic and biotic processes. Degradation is enhanced in warm alkaline waters. The peroxides result in rapid membrane disruption of algal cells. Best results typically occur prior to the onset of a significant bloom. Use of peroxides for submersed plant control is being investigated.
Carfentrazone	Hours to 1+ day	Hours to 1 + day	Carfentrazone is degraded via hydrolysis. The rate of hydrolysis is pH–dependent, with faster degradation occurring in higher pH waters.
Flumioxazin	Hours to 1+ day	Minutes to 1+ day	Flumioxazin is degraded via hydrolysis and the half-life has been calculated as ~5 days, 24 hours, and 22 minutes at pH of 5, 7, and 9 respectively. The pH can have a strong influence on efficacy of flumioxazin.

Systemic herbicides: contact exposure requirements, half-lives and degradation pathways

Compound	General Exposure Requirements	Typical half-life in water	Key degradation pathway and comments
2,4-D	Hours to days	4 to 21+ days	The key degradation pathway for 2,4-D is via microbial action. Water temperature and rate of microbial activity can have a strong influence on the rate of degradation. Photolysis also plays a role in degradation.
Triclopyr	Hours to days	4 to 14+ days	The key degradation pathway for triclopyr is via photolysis or sunlight. Time of year, water depth and water clarity can influence the rate of photodegradation. There is also some microbial action that results in degradation.
Glyphosate	Not used for submersed	Hours to 1+ day	Glyphosate is rapidly deactivated once it contacts the water column due to immediate binding with positively charged ions in the water. Once bound to cations, glyphosate is biologically inactive. Microbial action ultimately degrades the glyphosate molecule in the sediment.
Imazapyr	Not used for submersed	7 to 14+ days	The key aqueous degradation pathway for imazapyr is via photolysis. Time of year, water depth and water clarity can influence the rate of photodegradation. Microbial degradation can also play a role.
Fluridone	45+ days	7 to 30+ days	The key degradation pathway for fluridone is via photolysis. Factors such as water depth, water clarity and season of application can influence photolytic degradation. Microbial activity can also play a supporting role in degradation.
Topramezone	45+ days	14 to 30+ days	The key degradation pathway for topramezone is via photolysis. Factors such as water depth, water clarity and season of application can influence the rate of photolytic degradation. Microbial activity can also play a supporting role in degradation.
Penoxsulam	45+ days	7 to 30+ days	The key degradation pathway for penoxsulam is via photolysis. Factors such as water depth, water clarity and season of application can influence photolytic degradation. Microbial activity can also play a supporting role in degradation.
Imazamox	14+ days	7 to 14+ days	The key degradation pathway for imazamox is via photolysis. Factors such as water depth, water clarity and season of application can influence photolytic degradation. Microbial activity can also play a supporting role in degradation.
Bispyribac-sodium	45+ days	30+ days	Bispyribac-sodium is degraded via microbial action. Factors such as water temperature, trophic status, and plant density can influence the rate of degradation. Bispyribac-sodium generally has a long half-life; however, faster rates of degradation have been noted in a limited number of sites.

Chapter 12: Spray Adjuvants: A User's Guide

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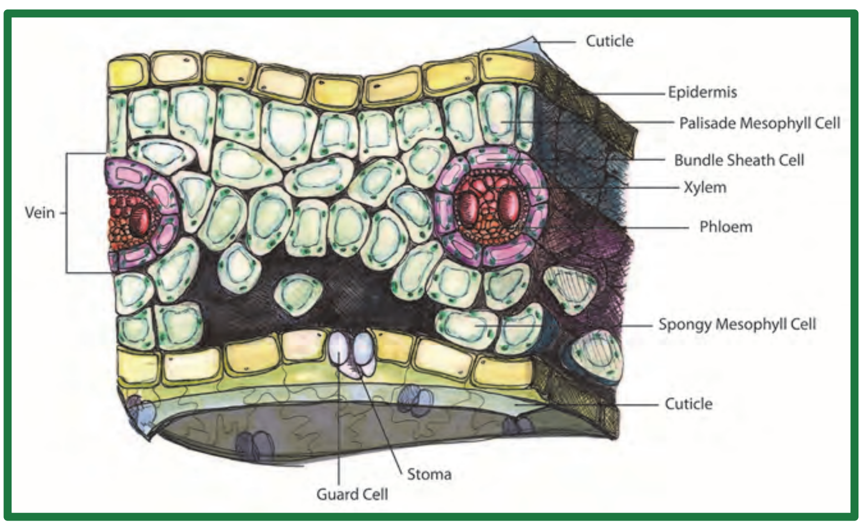
Introduction

There are around a dozen different herbicide products that can be used to manage undesirable aquatic plants. Although there is a great diversity of herbicide types, most products are applied either as specially formulated herbicide pellets (or granules) or as a liquid spray applied to water or plant stems and foliage. Of these techniques, spraying the foliage of undesirable plants is by far the most common practice. When making these applications, a spray adjuvant is often included to improve herbicide performance. There are many different adjuvant products available, so confusion often abounds and applicators may use products they don't need or fail to use products that could be helpful.

What is an adjuvant?

According to the *Weed Science Society of America*, an adjuvant is "any substance in an herbicide formulation or added to the spray tank to modify herbicidal activity or application characteristics" (Herbicide Handbook – 9th edition.)

There are two concepts that should be drawn from this definition: 1) an adjuvant is not herbicidal in and of itself, but rather works with the herbicide to improve efficacy, and 2) some adjuvants are used simply to improve the application and handling characteristics of a given herbicide. With this in mind, adjuvants are commonly divided into two primary categories: activator adjuvants and utility adjuvants. Activator adjuvants improve herbicide retention on the leaf and improve absorption into the leaf, while utility adjuvants are used to reduce spray drift, foaming in the tank and other factors not directly related to herbicide absorption or penetration into the plant.



Before we talk about how different adjuvants work, we should first examine a plant leaf to understand how herbicides are absorbed into a typical emergent or terrestrial plant. This leaf cross section shows many different tissue and cell types, but of particular interest are the large veins in the middle of the leaf. These veins contain the xylem and phloem, which are specialized tissues that transport water and nutrients throughout the plant. Many of our herbicides (such as glyphosate) are highly effective because they are systemic – meaning they are moved in the phloem throughout the entire plant and result in a total kill. But to kill the plant, these herbicides must first reach the veins in order to be transported. This is no easy task, since the herbicide must land on the leaf, diffuse through the tissues, and reach the active site at a high enough concentration to be lethal. The active site is the location in the plant where herbicides interfere with enzyme production or other biochemical pathways to kill the plant. Both sides of the leaf are covered in a layer of wax called the cuticle. The cuticle is important to the leaf, since wax repels water and prevents it from "leaking" out of the leaf. Most foliar herbicides are diluted in water, so the cuticle is a formidable barrier to herbicide entry into the plant.

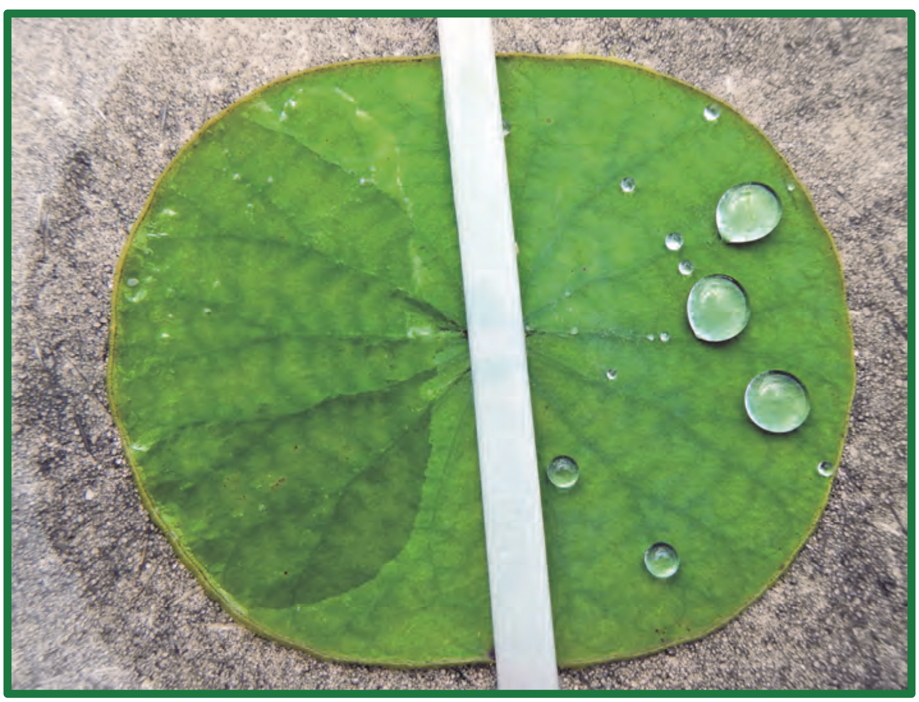
Activator Adjuvants

As stated previously, activator adjuvants do not have herbicidal properties, but rather work with the herbicide to improve efficacy. The primary role of an activator adjuvant is to help the herbicide breach the cuticle barrier and enter the leaf. This group of adjuvants is often further divided into two broad categories: 1) wetter/spreaders, also generically called surfactants, and 2) penetrants.

Wetter/spreaders

Wetter/spreaders are often called surfactants or stickers and are likely the most common type of adjuvant used to improve herbicide performance. Members of this class, which are specially developed soaps, are quite effective while also being inexpensive. Their main function is to not interact with the herbicide, per se, but to change the properties of the spray mixture in order to increase the movement of the herbicide into the plant.

Why is this important? Recall that the leaf's waxy cuticle repels water. At the same time, molecules of water are attracted to each other, which causes them to form round, bead-shaped droplets (think raindrops). When no surfactant is added to a spray solution, the absorption of herbicide into the leaf is limited for two reasons. First, the round, bead-like droplet prefers to stay as a round droplet. Therefore, as the droplet contacts the leaf surface (at a high speed since it is being propelled by a pressurized sprayer), the droplet will flex and then snap back into the round shape. This "flex and snap" action will commonly cause the droplet to bounce off the leaf. Second, if the droplet is retained on the leaf, the waxy cuticle repels it and only a small part of the droplet actually contacts the leaf surface. It is through this small area of contact that the herbicide has to diffuse from the droplet into the leaf – and it does so quite slowly. An additional challenge is that the droplet quickly starts to evaporate. If the droplet dries before the herbicide enters the plant, the herbicide will often turn into a crystal on the leaf (think of the white residue



left behind when saltwater evaporates). If the herbicide crystallizes, the likelihood that it will ever enter the plant is extremely low. The key is to get the herbicide from the droplet into the leaf as rapidly as possible. If the droplet bounces off, is repelled by the leaf, or dries too quickly, an insufficient amount of herbicide will enter the leaf and the weed will survive the treatment.

The addition of a wetter/spreader to the spray mixture greatly changes the spray droplet by lowering the surface tension of the water (the forces that make the water form a round bead) and provides three advantages. First, as the droplet contacts the leaf, the lower surface tension means that the droplet no longer wants to form a round bead; instead of bouncing off the leaf, the droplet flattens out and spray retention is greatly improved. Second, the flat droplet contacts much more of the leaf than a round droplet. This increased coverage allows better diffusion of the herbicide into the leaf since more surface area is exposed to the herbicide solution. Third, the addition of the surfactant slows down droplet evaporation, giving the herbicide more time to diffuse into the leaf.

One of the most common questions about wetter/spreader adjuvants is which brand is best. This is a difficult question to answer for many reasons, but in general, the best brand is the one you have successfully used for many years. Problems occur when an applicator attempts to buy the least expensive product (which often changes from year to year). The wisest strategy is to find a brand you are comfortable with and use that as much as possible. When trying a new product, start with a small amount and see if it fits your needs. The labels of many aquatic herbicides provide guidance regarding adjuvant selection; in fact, some products require the use of a particular type of adjuvant. However, don’t over-spend because doubling or tripling your adjuvant expenses may not be cost effective. Another common question is what rate of wetter/spreader to use. In general, 0.25% v/v (1 quart of product per 100 gal of spray mix) works great. There can be an advantage to increasing this to 0.5% v/v, but a rate higher than this rarely results in added benefit. Lastly, not all adjuvants are labeled for application in aquatic environments. Before applying any product to an aquatic system, check the label and make sure the product can be used in or around aquatic sites.

Organosilicones

Organosilicones are a distinct class of spray adjuvants. Their performance is similar to the wetter/spreaders, but organosilicones dramatically reduce – or totally remove – the surface tension forces of water. This causes the droplet to distribute itself into a very thin sheet across the leaf for maximum coverage. Organosilicones work quite well, but they are often more expensive and are not used as often as wetter/spreaders.

Penetrants

Penetrants are oil-based adjuvants and are most often crop oil concentrates and methylated seed oils. Using a water-dispersible oil adjuvant has a clear advantage over a traditional wetter/spreader. Recall that the wetter/spreader does little to improve herbicide uptake beyond ensuring that the droplet lies flat on the leaf. The herbicide must still diffuse through the cuticle to reach the cells and veins below. The waxy cuticle cannot be dissolved by water or a soapy wetter/spreader, but oil *will* soften or dissolve the cuticle. Therefore, as the spray droplet contacts the leaf surface, the oil-based adjuvant begins to dissolve these waxes. As the waxes are stripped away, the herbicide can easily penetrate the leaf and be transported to the regions where it can be most effective.

Since these adjuvants help the herbicide penetrate into the leaf, weed control is often greater with an oil-based penetrant than with a wetter/spreader. Penetrants are typically used on weeds that are larger and more difficult to control, or on species with leaves that are particularly waxy (think waterhyacinth – Chapter 15.7). Penetrants can also be useful if the weather has been dry, because plant cuticles may thicken to reduce drought stress. If weed control must be performed during these times, an oil-based adjuvant may be essential to help dissolve these thick leaf waxes and facilitate herbicide uptake. You should take into consideration that penetrants are usually applied at a 1% v/v (1 gal per 100 gal of spray mix), while wetter/spreaders are added at 0.25% v/v.

It is important to note that penetrant adjuvants are not always the best solution. For example, glyphosate does not perform as well when oil-based adjuvants are used. Conversely, other herbicides should only be used with penetrant adjuvants. It is, therefore, important to read the herbicide label so the recommended adjuvant can be used. Also, since oil-based adjuvants strip away leaf waxes, they can injure desirable plants that are not normally affected by the herbicide. For example, 2,4-D is often used to control broadleaf weeds in grass because grasses are not damaged by 2,4-D. However, if 2,4-D is applied with a high rate of an oil-based adjuvant, the penetrant oil can actually burn the desirable grass since the cuticle is eroded and the cells beneath die when exposed to the environment. The grass will recover, but the injury can be unsightly for a period of time.

Utility Adjuvants

Utility adjuvants have a very different role and purpose than activator adjuvants. Activator adjuvants actively promote herbicide uptake into the plant by influencing the spray droplet, the plant cuticle, or both, but utility adjuvants improve the efficiency of the spray operation. There are many types, brands, and blends of utility adjuvants that have value for their specific uses, but their benefit is often situational and may not provide an advantage across all conditions. Therefore, it is important to understand what these products are designed to do so they can be used to maximum effect.

Defoamers

Wetter/spreader adjuvants are commonly added to improve herbicide performance. These adjuvants are soaps, so foaming is common when the tank is refilled. A small amount of defoamer added prior to tank filling can prevent bubble formation and greatly improve the efficiency of the application. Consider the photo shown at left; though a foam-forming adjuvant was used in both beakers, defoamer was only added to the container on the right. Adding defoamer after a large quantity of bubbles has formed requires much more product and time to clear the tank for refilling. It is important to be proactive and add defoamer to the spray tank before adding soapy adjuvants.

Water Conditioners

All natural waters contain dissolved minerals, including iron, magnesium, calcium, and aluminum, and these minerals can change the properties of water. For example, the amount or type of minerals in water is what makes water from one region of the country taste different from another. The mineral content of water used in a spray tank can affect application because the minerals listed above are all positively charged, while many commonly used herbicides are negatively charged. When these negatively charged herbicides and positively charged minerals are dissolved in a spray tank together, they naturally attract each other like magnets.

This causes problems because herbicides are highly specific and work by binding to exact places on exact enzymes within the plant. Also, they diffuse through plant cuticles in a specific manner. When a herbicide is bound to a mineral such as calcium or a magnesium complex, it may be unable to enter the plant and work properly. If many herbicide molecules are bound to and deactivated by mineral complexes, they will lose their herbicidal activity and the application will be less effective.

Water conditioners were developed to minimize the impact of dissolved minerals on herbicides. One of the most common conditioners is ammonium sulfate [$(NH_4)_2SO_4$]. Ammonium sulfate and other water conditioners bind to minerals that are dissolved in the water, which makes the minerals unavailable to bind to the herbicide and prevents the herbicide from being deactivated. If mineral content is high (especially with aluminum, iron, calcium and magnesium, which are often considered to be most detrimental), it might be useful to add a conditioner to the water being used to dilute the herbicide.

If all water contains dissolved minerals, do all applications require water conditioners? Not necessarily; it depends on how high the mineral concentration is in the mix water and how many herbicide molecules could be deactivated. In general, the higher the mineral concentration in the water, the greater the likelihood of herbicide deactivation, and the more likely the need to use a conditioner.

Things to consider:

- The addition of a water conditioner may not always be needed because not all aquatic herbicides are affected by water hardness, so consult the label. If herbicide efficacy is lower than expected, send a water sample to a lab for analysis. If the results say your water is "hard" or "extremely hard", consider adding a water conditioner.
- If you are using a dry ammonium sulfate product, be sure to use "spray grade". If not, you may have difficulty getting the product to fully dissolve in water. Spray grade or liquid ammonium sulfate products avoid this problem.
- Add the water conditioner to the tank before the herbicide. Fill the tank 25% full, add the water conditioner, fill to 50%, add the herbicide and fill to 100%.
- Always check the herbicide label before adding a water conditioner. Some labels specifically state that NO ammonium sulfate may be used in the application. Remember, the label is the law.

pH Buffers

It can also be important to know the pH of the water used in a tank mix. pH is measured on a scale of 0 to 14 and describes water as acidic (pH 0 to 6.9) or alkaline (pH 7.1 to 14). We often think water is neutral (pH 7), but that is rarely the case. For example, if you live in an area with limestone in the soil, your water pH may be 8.0 or higher. Water pH is important because acidic or alkaline water can react with herbicide molecules, which can affect efficacy.

The majority of herbicides we currently use are classified as "weak acids" and they perform better in an environment that is slightly acidic – ideally, water with a pH of 4.5 to 6.5. Therefore, mixing a weakly acid herbicide in alkaline water with a pH of 8 could cause the herbicide to begin to degrade and become less effective.

Does this mean that spray water must always be acidified? Not necessarily. Although herbicide breakdown in the tank can occur if the water pH isn't correct, this may never be an issue if you mix and spray quickly. Regardless, read the product label to determine whether acidification of tank water is necessary. Some labels recommend that herbicides be diluted with water that has a pH of 6 to 8, while others recommend water with a pH of 4 to 7. If water pH is in the recommended range, no action may be required. However, pH testing can be very useful if you are attempting to optimize your spray program.

Spray Dyes

Spot-spray applications can be a highly efficient, selective and cost effective way to manage sporadic populations of unwanted plants. However, these plants are often randomly distributed across a landscape, which complicates spot-spraying. Invariably, some patches will be treated twice, while others are missed entirely. If you plan to perform spot-spray treatments, a non-toxic dye can be added to the spray mix to ensure that each and every weed is treated once.

A spray dye is a colorant that stains the weeds that have been sprayed. This gives the applicator an immediate visual cue that a particular weed has been sprayed, or missed. Many different brands and colors of spray dye are currently available, but blue is the most common. The color fades and is gone within 1 to 5 days after spraying.

Drift Reducers

Herbicides are a powerful and useful tool to manage unwanted plants while preserving and encouraging growth of desirable species. However, a constant concern is damage to desirable plants that occurs when the herbicide spray drifts, or is blown outside the treatment area. Therefore, care should be taken to avoid or minimize herbicide drift.

Sprayers work by pressurizing the herbicide solution and forcing it through a hose to a spray nozzle. When the liquid solution strikes the specially designed nozzle, it fragments (or shears) into individual droplets. For example, note the small, drifting droplets being formed during the high-pressure herbicide treatment shown here. Nozzle type and sprayer pressure affect droplet formation and work together to form large or small droplets. Small droplets are of the greatest concern because they are easily moved by wind currents. One way to manage the proportion of small droplets formed is to include a drift-reducing agent in the herbicide mixture, which will "thicken" the spray solution. Thicker liquids resist shearing into small droplets, so fewer small droplets are formed and the risk of drift is reduced.

Though drift reducers can be quite effective, other techniques should also be employed to manage drift.

1. Spray at the lowest pressure possible. As pressure in the sprayer increases, more small droplets are formed.
2. Avoid spraying in high wind. The higher the wind speed, the more likely droplets will drift. Also, high wind can carry small droplets exceptionally long distances.
3. Avoid spraying into the air when possible. It is often necessary to spray into the air when undesirable trees must be managed. However, spraying in this manner increases the likelihood that droplets will drift.
4. Pay close attention to your surroundings. If valuable or highly sensitive plants are nearby (for example, gardens), closely examine what and where you are spraying and evaluate the likelihood of drift occurring.
5. Although most herbicide drift issues arise from physical movement of spray droplets, some herbicides can turn into a gas and drift as a vapor, particularly on very hot days. This is most common with herbicides such as 2,4-D and triclopyr. Products that are especially prone to drift will provide this information on the label, along with guidelines and requirements to reduce the occurrence of drift.

Conclusions

Adjuvants are not herbicides and do not directly control unwanted plants, but they work with herbicides to greatly improve efficacy and productivity of herbicide applications. With that in mind, here are a few things to keep in mind when considering the use of an adjuvant:

- Before making an application, ensure that the target weed will be adequately controlled by the selected herbicide. Read the herbicide label and note the appropriate plant size and application timing for the target weed. If the wrong herbicide is chosen, or applied in an inappropriate manner, the addition of an adjuvant will rarely improve control.

- Be aware that some adjuvants are blends of several products. For example, it is possible to buy products that adjust pH and act as a wetter/spreader. Before you purchase a blend, make sure all of the components are necessary for the application. Using a blended product is not likely to decrease herbicidal activity, but it can result in an unnecessary increase in cost.

- Some manufacturers suggest that a particular adjuvant is so effective that the application rate of the herbicide can be reduced. Caution should be exercised before reducing a recommended herbicide use rate. Herbicide labels are written after a great amount of data is collected over several years at many locations, so recommended label rates and application methods are time proven. Expecting an adjuvant to do the work of a herbicide can result in reduced efficacy, and more often than not, an applicator is better off following the herbicide label recommendations.

- It has been suggested that the addition of common dish soap or fuel oils (such as diesel) to the spray tank may be equally effective as proper spray adjuvants. This is simply not true. Spray adjuvants have been specifically formulated to enhance herbicide performance without significantly damaging the plant. Adding soaps or fuel oils can disrupt leaf tissue, result in significant foaming and increase expenses, while potentially decreasing herbicide activity. An adjuvant that was specifically designed for the particular application should always be used instead of common household products.

Adjuvant technology has improved dramatically over the past 50 years, and many of these products are highly reliable and effective. However, reading all product labels is essential to ensure that all treatment components are used for maximum effectiveness in order to improve the efficacy of any weed management program.

Photo and illustration credits:

Page 89: Cross section of a leaf on a typical terrestrial or emergent plant. Modified from an image by Ninghui Shi. Used with permission.
Page 90: Water on a lotus (*Nelumbo lutea*) leaf with (left) and without (right) a surfactant; Lyn Gettys, University of Florida
Page 92: Beakers with and without defoamer; Jason Ferrell, University of Florida
Page 94: Using a dye while spot-spraying; Thomas D. Brock, University of Wisconsin-Madison
Page 95: Spray drift from a high-pressure herbicide treatment performed at a distance from the target; Ken Langeland, University of Florida

Chapter 13: The Biology and Management of Algae

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Introduction

Algae are found in all salt and freshwaters worldwide. Although algae are very simple in their structure and sometimes consist only of a single cell floating in water, they are tremendously important for the health of our planet. Algae provide the base of food chains that support whales, seals, sharks and all other marine organisms in the oceans. In freshwaters, they also support food chains that lead to animals as diverse as bass, bald eagles and grizzly bears. Another essential role of algae is that they produce between 40-50% of the oxygen that we breathe through the process of photosynthesis!

The number of algae species is unknown, but it is likely more than 100,000, ranging from single cells to the large seaweeds found along our coastlines. Identification of freshwater algae can be difficult because the cells, or even clusters of cells, tend to be small and a microscope is usually required for accurate identification. In addition to cell shape and size, a key feature for proper identification is the color. Although all algae contain the green pigment chlorophyll, other pigments can also be present and can give the organisms different colors. Green algae are green because of chlorophyll, but diatoms and dinoflagellates are brown because xanthophyll pigments are present in higher concentrations than chlorophyll. The blue-green algae (also called the cyanobacteria) contain phycocyanin, a blue pigment that, along with chlorophyll, gives the cells a bluish-green color under the microscope.

Algae grow rapidly and reproduce primarily by cell division and by the formation of spores. They do not produce flowers or seeds. Most of the time people don't notice them, even though they are present in most bodies of water from bird baths to large lakes. Under certain circumstances, algae grow so prolifically that we do notice them. This is when water turns pea-soup green, or when masses of what is commonly called "moss" float on the surface of the water. It is these algae that often need to be managed because of the problems they can cause.

In addition to being unsightly, excessive algal growth (often called blooms) can lead to fish kills. This happens when the algae in a body of water die (crash) all at once. Crashes can be caused by a variety of factors including cell aging, nutrient depletion or sudden changes in weather, such as a shift in water temperature or a period of prolonged cloudiness. Bacteria and fungi that break down the dead algal cells (organic matter) require large amounts of oxygen; as algae decompose, oxygen in the water is depleted, which results in oxygen-starved and dying fish. Since it is difficult to predict when and under what circumstances an algal bloom will crash, it is essential that waters be managed so that excessive growth does not occur. Once a body of water becomes infested with algae, control measures can be used to reduce the frequency and severity of blooms, but it is extremely difficult to eliminate the problem. Because of the many different types of algae and the need to initiate control measures so that fish kills do not occur, it is usually best to consult with a professional lake or pond manager for advice on management strategies. Hiring a certified aquatic pesticide applicator knowledgeable about algae control is also a good move when chemical treatments are recommended.

The algae that cause obvious changes to the color of the water itself are called phytoplankton. These algae consist of single cells or clusters of cells that can only be identified with a microscope. Another major group of algae forms long filaments, or strings, which get tangled together and form clumps or mats. Although these mats start growing along the bottom of a body of water, the oxygen they produce from photosynthesis gets trapped as air bubbles in the mats, causing them to detach from the bottom of the pond or lake and float to the surface. This is when mat-forming algae become visible and cause problems when people try to fish, swim or boat through the mats.

A third group of freshwater algae is the Chara-Nitella group. These algae look like flowering plants because they appear rooted and have "leaves" that are arranged along a stem. Chara, also called stonewort, usually grows in very hard water and is often calcified (covered with scale) and brittle, whereas Nitella tends to grow in softer waters. These algae provide valuable habitat for fish and stabilize sediments; however, in shallow water some species can grow to the surface and be troublesome.

Algae are usually identified by the taxonomic group to which they belong. From a management standpoint, the two major groups are blue-green algae and green algae. Phytoplanktonic blue-green algae are usually responsible for the pea-soup green color of water. These algae can be extremely harmful not only because they have the potential to cause fish kills by depleting oxygen when they die, but also because some produce toxic compounds that can poison livestock, pets and wild animals that drink contaminated water (Chapter 14). In a few instances, humans have been sickened by drinking contaminated water; also, deaths have been recorded outside the United States. Such poisoning is very rare, but it is always wise to prohibit people from drinking or swimming in water that is dark green in color. Blue-green algae can also cause water to taste or smell foul and can cause fish flesh to taste musty.

Some filamentous blue-green algae form mats but most species of mat-formers are green algae. Mats that float on the surface often get “sunburned” from exposure to high light. The tops of the mats will look yellow; however, if the mat is pulled apart, the green color of the filaments or strings below the surface will be obvious.

Almost all of the algae that cause problems are native to the US and humans have been living with them for centuries. The conditions that promote algae include those typical of small, shallow ponds or lakes that become very warm in the summer and have little or no wave action. The main reason algae are such problems now is because of the impacts we humans have had on our water resources. Like other plants, algae require light, water and carbon dioxide to survive and grow. Light is seldom a problem in shallow waters. Algae and plants also need nitrogen, phosphorus and other nutrients in order to grow. The increase of nitrogen and phosphorus in lakes, rivers and ponds from many sources – including sewage and runoff from fertilized lawns, farm fields and livestock pastures – has caused algal blooms to proliferate in many bodies of water. Excessive algae growth is a key indicator of eutrophic conditions in lakes and ponds (see Chapter 1 for a discussion of trophic states). Even the Gulf of Mexico, which receives nutrient-laden waters from the Mississippi River, has suffered from algae blooms and fish kills.

What can be done to reduce the incidence and severity of an overabundance of algae?

Nutrient reduction and inactivation

A difficult but essential first step is to reduce the factors that cause algae to grow. This is most easily accomplished when constructing a body of water such as a pond. New ponds should be situated away from obvious sources of nutrients and dug deeply enough to prevent light from reaching the bottom. Unfortunately, reducing the input of nutrients into an established pond or lake can be quite difficult. Good watershed management plans are required to reduce obvious sources of nutrients such as upstream inputs from sewage outfalls, lawn or farm field fertilization and livestock operations. Every lake association should initiate and follow through on a watershed management plan. Nutrient sources from around the shoreline – including fertilization of lawns close to the water’s edge – should be reduced as well. Fertilization should be prohibited within at least 10 to 20 feet of the shoreline and fertilizers without phosphorus should be used in areas that have to be fertilized.

Turfgrasses are usually maintained along the shoreline, but these grasses have shallow roots and do little to prevent erosion. Recent interest has focused on planting shorelines with native emergent vegetation such as sedges, rushes and colorful plants such as pickerelweed, cardinal flower and arrowhead. These native plants, which are sold by companies promoting environmental restoration, have longer and more substantial root systems than turfgrasses, which allows them to hold soil better, prevent erosion and potentially absorb more nutrients from subsurface runoff.

Some nutrient inactivation methods in the water itself can help reduce algae blooms. Alum is a material that combines with phosphorus and causes it to precipitate to the bottom so that it is no longer available for algal growth. However, the long-term value of an alum application can be greatly reduced if inputs of phosphorus from the shoreline and watershed continue unabated. Also, alum lowers the pH of the water, which can be detrimental to fish life. Buffers are usually added to prevent this, so the application of alum is best left to an experienced contractor.

Another option is to install aerators. The introduction of oxygen into a body of water changes the chemistry of the water so that phosphorus is precipitated to the bottom. Aeration is also valuable for fish life and the introduction of air (oxygen) to the water promotes the bacterial breakdown of

organic matter that has accumulated on the bottom over time. Fountains that just spray water from the pond surface are not effective aerators because they only aerate the top few feet of water. Effective aeration devices are those that deliver oxygen to the bottom waters. They can be purchased or constructed and work on one of two principles. One is to pump air into weighted tubes along the pond bottom. The oxygen bubbles into the water through holes in the tubes. This is the most commonly used device in ponds. The second type of aerator, called a hypolimnetic aerator, moves low-oxygen bottom water to the surface, oxygenates it and then recirculates the aerated water to the bottom of the lake. These units are typically used on stratified lakes where the bottom waters are cold and the aerated cold water must be returned to the bottom in order to support cold-water fish.

Several enzyme and bacterial products are on the market and claim to reduce the amount of nutrients available to algae. The enzymes are thought to break down organic matter so that it is easier for the natural bacteria to take up the nitrogen and phosphorus that is released during decomposition of the organic matter. Adding a product that contains bacteria is intended to supplement the natural bacteria population. In theory, bacteria are better competitors for nutrients than are algae. Consequently, the bacteria should reduce the amount of nitrogen and phosphorus that is available for algae growth, resulting in clear water. Unfortunately, very little research has been conducted on the effectiveness of these products and testimonials are mixed, so their usefulness is controversial.

Nutrient reduction/inactivation strategies can help improve the overall health of a body of water. On the other hand, they seldom cure algae problems because it is usually difficult to identify the source of inputs of nitrogen and phosphorus. Is it lawn fertilization? Is it from the recycling of nutrients from the lake or pond sediments? Is the soil naturally rich in nutrients? Or is it from a number of other potential sources? Without this information, it is difficult to develop a nutrient reduction strategy that results in relatively rapid and long-term control of algae.

Other control options

Reducing light penetration through the use of EPA-registered dyes can be helpful in algae control. Dyes should be applied early in the growing season before algae appear at the surface. However, since algae often start growing in shallow water, the dye may not be at a high enough concentration in those areas to sufficiently reduce algal populations. Once algae begin to grow in shallow water, they can then spread to the upper portions of the deeper water relatively quickly. Since the dye concentration in the water must be maintained throughout the growing season, dyes are more effective on bodies of water that have little to no outflow. Dyes alone are seldom effective for controlling algae, but they can be used after an algicide treatment to reduce regrowth.

Mat-forming algae can be raked out manually or with mechanical harvesters. Raking is typically done around boat docks and in swimming areas. Since mat-formers are mostly free-floating, new mats can rapidly reinfest an area that has been raked. The only biological control agent (Chapter 8) being used for algae control is the tilapia (*Tilapia zillii*), a fish that has been introduced into and can only survive in waters of the southern US. Tilapia are stocked in very high numbers in the cooling reservoirs of some southern power plants, but they are not used by the public. The grass carp or white amur (Chapter 10) does not feed on phytoplankton. When young, grass carp will consume some mat-forming algae, but they do have preferences (slimy algae are rejected; coarser algae might be eaten). As the grass carp age, they tend to feed more on submersed plants than on algae.

Algicides

Direct control of algae is most frequently accomplished with algicides. Copper sulfate (Chapter 11) has been used for algae control since the early 1900s and is used on more surface acres of water than any other product that controls algae or aquatic plants. One of the benefits of copper sulfate is that phytoplanktonic blue-green algae are more sensitive to it than are phytoplanktonic green algae. As a result, noxious blue-green algae can often be removed without harming the green algae, which are usually desirable because they are an important component of the aquatic food chain. Both copper sulfate and the copper chelated products are also used to control mat-forming algae. Liquid formulations of chelated copper products are particularly effective for this purpose because they can be easily mixed with water and sprayed directly onto the algae mats.

Copper sulfate and copper chelates are widely used throughout the world to treat reservoirs that collect and store drinking water. Our ability to safely treat water with copper products to control blue-green and other algae is predicated on the low dosages used, the fact that copper precipitates out of the water and into the sediments within several days in moderately hard to hard waters, and on the inability of copper to bioaccumulate (build up over time) in fauna in the food chain. Animals and humans actually require small amounts of copper in their diets and the element is often included in human vitamin supplements and in animal feed. Copper from treated water that is consumed by humans and other animals passes through the body and is expelled in the urine rather than moving into the body's tissues. Copper products can be applied to water with no restrictions on water use (e.g., swimming, fishing, drinking); however, they should be used very carefully or not at all in waters that contain sensitive fish species such as trout, koi and goldfish.

Copper products are effective and widely used, but they do not solve the underlying issue of why the algae are there in the first place. These algicides do offer short-term relief, which can be extremely valuable in terms of preventing fish kills (if treatment is initiated before the bloom becomes severe) and opening up the water for fishing, swimming and other activities. However, it is extremely unlikely that copper applications will kill all the algae or their spores, so regrowth almost always occurs. Furthermore, copper products are very short-lived in the water and algae can start to reappear quickly, sometimes within several weeks. As a result, the potential for retreatment has to be part of any management plan that uses copper products.

There are very few alternatives to copper for direct algae control. The amine salt of endothall has algicidal activity and can be sprayed along the edges of ponds for control of mat-forming algae. Read and follow the herbicide label for endothall carefully as this herbicide can be toxic to fish if not used correctly. Compounds that are based on sodium carbonate peroxyhydrate release hydrogen peroxide (Chapter 11) into the water, which rapidly kills the algal tissue it comes into contact with. Unlike copper, hydrogen peroxide breaks down rapidly in water to produce hydrogen and oxygen, so it leaves no residues. A uniform application of the sodium carbonate peroxyhydrate granules is necessary to ensure optimum results because the hydrogen peroxide products only control algae that come into direct contact with the granules. Since hydrogen peroxide products are fairly new to the market and have not been available for very long, they have not been tested for effectiveness as extensively as copper. Research is still needed to determine which algal species are most effectively controlled by these products.

Another chemical approach that has received much publicity is the use of barley straw for algae control. English researchers found that bundles of barley straw placed in water released a toxin that killed algae as the straw decomposed. A number of barley products, including barley straw extracts, are on the market. The potential of the toxin to kill algae is well established but the conditions under which the activity occurs are as yet unknown. In other words, we do not know which algal species are affected nor do we know what effects water temperature, water hardness, nutrient status, etc. might have on the effectiveness of this treatment. Anecdotal evidence suggests that the method is inconsistent; that is, it might work on one body of water but not on another, and the reason for this is not known. Caution, along with much reading and study, are recommended before attempting to use barley straw to control algae.

Summary

Algae problems are usually the result of too many natural- or human-derived nutrients in a body of water. As long as light, nutrients and water are available, something green will grow. Even swimming pools can develop algae problems because different types of algae have different nutrient requirements and all water – even rainwater – contains nutrients. The algae that cause most problems are blue-green algae and mat-forming green algae. Due to their diversity and ability to reproduce quickly, algae are difficult to control. Many products claim to reduce algal populations, but unless they make direct claims of algae control, they do not have to be registered for use with the EPA and are largely untested. Products that are registered with the EPA include some dyes and algicides such as the copper, peroxide and endothall products. Specific use directions are explicitly stated on the labels, which are excellent sources for further information.

For more information:

•Algae control with barley straw (Ohio State University Extension Fact Sheet)
http://ohioline.osu.edu/a-fact/0012.html
•Algae: some common freshwater types (Microscopy UK)
http://www.microscopy-uk.org.uk/index.html?http://www.microscopy-uk.org.uk/pond/algae.html
•Blue-green algae (cyanobacteria) blooms (California Department of Public Health)
http://ww2.cdph.ca.gov/healthinfo/environhealth/water/Pages/bluegreenalgae.aspx
•Blue-green algae photo gallery (Vermont Department of Health)
http://healthvermont.gov/enviro/bg_algae/photos.aspx
•Harmful algal blooms (HABs) (Centers for Disease Control and Prevention)
http://www.cdc.gov/hab
•Identifying and managing aquatic vegetation (Purdue University)
http://www.extension.purdue.edu/extmedia/APM/APM_3_W.pdf

•Plant identification: algae, AQUAPLANT (Texas A&M University)
http://aquaplant.tamu.edu/database/index/plant_id_algae.htm
•Surf your watershed (United States Environmental Protection Agency)
http://cfpub.epa.gov/surf/locate/index.cfm

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Page 101: Filamentous algae; Andy Price
Page 102: Algae bloom; Carole Lembi, Purdue University

Chapter 14: Ecology and Management of Noxious Algae

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Introduction

Algae (singular *alga*, Latin for "seaweed") are a large and diverse group of structurally simple organisms that range from small, unicellular species to large, multicellular forms, such as the giant kelps that grow to more than 200 feet (65 meters) in length. In fresh waters, algae typically float in the water column (planktonic algae), form mats on the bottom of the waterbody (benthic or sediment algae), or form coatings on submersed structures (periphytic or attached algae). Although the shapes and sizes of algae range widely, they are considered structurally "simple" because their cells are not organized into the distinct organs such as roots, stems, leaves, flowers, and fruits that are found in land plants. Most algae are photosynthetic and use sunlight to "fix" carbon and produce sugars, but some unicellular species are unable to photosynthesize. While cyanobacteria (commonly called "blue-green algae") have traditionally been considered algae, recent scientific studies usually exclude them due to important structural and physiological differences. However, for purposes of this discussion, cyanobacteria will be included as algae.

Algae are at the base of the food web and are considered "primary producers" in aquatic systems because they provide sugars and chemical energy for other organisms (Chapter 1). Algae are a crucial food source for invertebrates and fish, as well as frogs and other fauna that inhabit a system. Although algae occupy a critical niche in aquatic environments, many algae can quickly grow to densities that become problematic or noxious. Noxious algal growths or "blooms" have compromised water resources throughout the world and have impeded the use of infested waters for wildlife, aquaculture, drinking, irrigation, recreation and industrial operations. Excessive growths of algae can change pH and water quality, reduce dissolved oxygen (which can kill fish and other aquatic life), and cause foul tastes and odors. In addition, several groups of algae produce potent toxins that can be deadly in even small quantities.

Tremendous economic damage can result from noxious algal growths. Annual losses of up to $2 billion in the US can arise from the inability to use a water resource for purposes such as domestic supply, industrial uses, irrigation, fire suppression and navigation, and can lead to declines in recreational uses and decreases in property values.

Resource managers recognize that algae must be managed in critical aquatic systems to maintain the designated uses of the water. When excessive algae growth occurs, “adaptive water resource management” is usually implemented to maintain the system and its uses. Adaptive water resource management involves careful consideration of all available options to manage or control algae and vascular aquatic plants to restore the uses of water resources. Managing noxious algal growth requires actions that may include mechanical, physical, biological, or chemical strategies, alone or in combination. Although it may be beneficial in the long run to reduce the human contributions (such as nutrient runoff) to algae blooms, many algal species can double their population size in two days or less, so immediate action is usually needed to manage infestations. In these time-sensitive situations, algaecides can serve as a first line of defense because they are cost effective, environmentally sound, socially accepted, and work quickly to control excessive populations of algae. In order to efficiently and effectively use algaecides, water resource managers must rely on their knowledge of the aquatic system (i.e., nontarget species, water quality, etc.), the algae to be controlled and the algaecides labeled for use in the system.

Algaecides are available in several different active ingredients and formulations. Algaecide active ingredients that are registered for use with the US Environmental Protection Agency (USEPA) include copper salts and formulations, synthetic organic compounds, and hydrogen peroxide (Chapter 11). Each algaecide has unique properties that should be carefully considered and evaluated prior to use in a water resource. The adoption of the National Pollutant Discharge Elimination System (NPDES) has resulted in the requirement for a permit to apply algaecides and other pesticides over or near waters of the state or nation (USEPA 2011**)**. Materials that are not registered as algaecides by the USEPA will not be considered in this discussion.

The application of an algaecide can rapidly restore the uses of an aquatic system; adaptive water resource management should then be employed to develop strategies to prevent or mitigate future algal issues. Prevention measures such as the control of algal movement in bilge waters and bait buckets should be undertaken. Other practices, such as reduction or elimination of runoff and nutrient control in the watershed, may be helpful in the long term, but are unlikely to provide immediate relief for excessive algae problems.

Algal toxins in freshwater systems

This section will focus on toxin-producing species of freshwater algae, which can adversely affect other algae, invertebrates, fish and mammals. Algal toxins are problematic in fresh waters when they are produced in sufficient quantities with sufficient potency to cause direct toxicity to organisms, decrease feeding and growth rates, and cause food safety issues. Production of algal toxins may be associated with a “bloom” or exceptionally dense growth or accumulation of algae. The term “Harmful Algal Bloom” (HAB) has been used to describe a proliferation, or "bloom," usually of phytoplankton. Because phytoplankton serves as the base of most aquatic food webs, the impact of these blooms can be devastating for consumers throughout the food web and for other flora or fauna in the affected ecosystem. Even severe blooms of non-toxic algal species can spell disaster for animals in freshwater aquatic systems since massive quantities of phytoplankton deplete oxygen in the shallow waters of many systems. Recently, the world's coastal and inland waters have experienced an increase in the number and type of HAB events or the observation of those events has become more intense. Scientists are unsure of the causes for this trend. Possibilities range from natural causes such as species dispersal to human-related causes like nutrient enrichment, shifts in global climate and transport of algal species by ship ballast water.

The species of freshwater algae that cause HABs, as well as their effects, vary widely. While some are toxic only when they achieve high densities, others can be toxic at very low densities (only a few cells per liter). Whereas some blooms discolor the water (thus the terms "green scum", "red tide" and "brown tide"), others are almost undetectable by unaided visual observation. The effects of HABs generally fall into two major categories: 1) public health and ecosystem effects, and 2) economic impacts. Broadly, public health and ecosystem effects can include factors such as:

1. Filter feeding shellfish (e.g. clams, mussels) may accumulate algal toxins by feeding on the toxic phytoplankton, sometimes at levels potentially lethal to humans or other consumers;
2. Potential fish, shellfish, and bird kills, occasionally invertebrate and mammal kills;
3. Decreased light penetration can alter ecosystem function and structure;
4. Discoloration of water can be aesthetically unpleasant;
5. Toxins or other compounds released by the algae can kill fauna directly or result in low oxygen conditions as the bloom biomass decays (especially critical where fauna cannot escape);
6. Blooms can be harmful to other algae or primary producers and the food webs that are dependent on them; and
7. The effects of long-term or chronic exposures to algal toxins on shoreline residents.

Direct economic impacts caused by HABs include loss of income for commercial fishermen, loss of food for subsistence fishermen, and consumer concerns regarding food safety, as well as declines in property values.

This chapter is focused on algal toxins in freshwater systems in the US. The chapter is limited to toxins produced by cyanobacteria, golden algae and euglenoids. Other algae (e.g., *Chrysochromulina*, etc.) that produce both toxins and/or taste-and-odor compounds can be important, but are not included in this discussion. Also, some more recent discoveries, such as the *Stigonematales*-like cyanobacterium that has been implicated in avian vacuolar myelinopathy, are not included since sufficient information for management has not been developed at this time.

Cyanobacteria: the blue-green algae

Cyanobacteria (blue-green algae) are geologically ancient, broadly distributed inhabitants of fresh, brackish, marine and hypersaline waters, as well as terrestrial environments, and grow in diverse habitats ranging from thermal springs to the arctic. Although cyanobacteria are classified as bacteria as opposed to algae, they are photosynthetic in aquatic systems. In fact, cyanobacteria are much larger than other bacteria and are major contributors to global photosynthesis and nitrogen fixation. Cyanobacteria occur in unicellular, colonial and filamentous forms; they grow under a wide variety of conditions and can become the dominant algae in nutrient-rich water bodies. Cyanobacteria can form blooms so thick that the surface of the water appears to be covered with blue-green paint. Several cyanobacteria in the US produce substances that cause taste and odor problems in water supplies and aquaculture. Some species of blue-green algae, particularly

Anabaena and *Microcystis*, are widely distributed in the US and can produce toxins that are poisonous to fish and wildlife that drink toxin-contaminated water. In other parts of the world, there are documented cases of blue-green algal toxins harming humans that have consumed toxin-tainted waters.

Cyanobacterial ecology in freshwater systems

Cyanobacteria are most abundant in eutrophic conditions, but they can readily colonize most freshwater systems and can rapidly grow to great masses. Cyanobacteria can rapidly overtake a system and cause "blooms" that render the water resource unstable or unusable. The occurrence and abundance of particular cyanobacteria in a freshwater system depend on a variety of ecological factors, including nutrient status, salinity, light conditions, turbulence and mixing, temperature and herbivory. In most freshwater systems, true algae may grow faster than cyanobacteria. However, cyanobacteria can seize the advantage in eutrophic situations by out-competing algae for nutrients, thriving in low dissolved oxygen and photosynthesizing more efficiently at lower light levels. Cyanobacteria are also less affected by turbidity, high concentrations of ammonia and warmer temperatures than are algae; in addition, they may produce chemicals that inhibit the growth of competing algae and reduce grazing by invertebrates.

Cyanobacterial toxins in freshwater systems

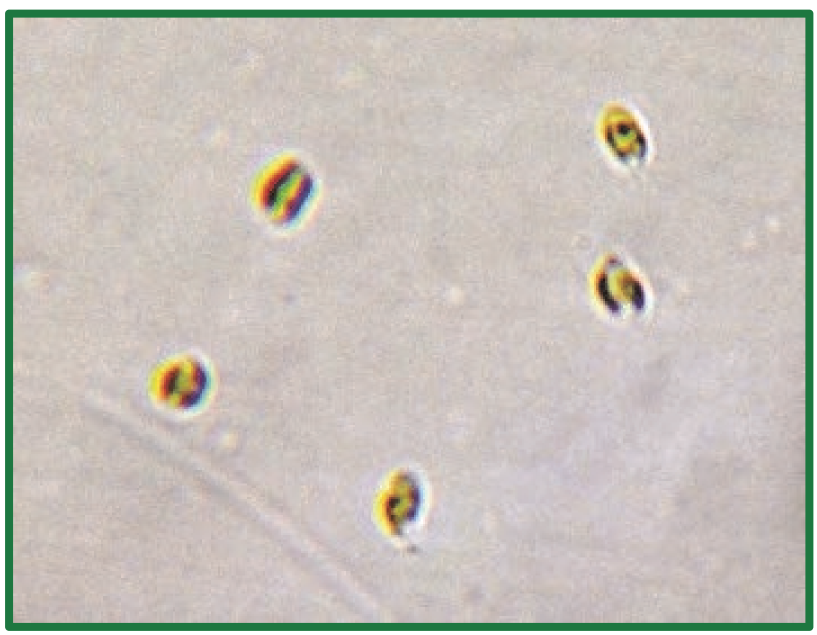
A number of types of cyanobacterial toxins are produced by various species of blue-green algae, but most cyanotoxins are classified as either neurotoxins or hepatotoxins. Neurotoxins attack the nervous systems of vertebrates and invertebrates; symptoms of neurotoxin poisoning include loss of coordination, twitching, irregular gill movement, tremors, altered swimming, and convulsions before death by respiratory arrest. Neurotoxins are produced by several genera of cyanobacteria including *Anabaena*, *Aphanizomenon*, *Microcystis*, *Planktothrix*, *Raphidiopsis*, *Arthrospira*, *Cylindrospermum*, *Phormidium* and *Oscillatoria*. Neurotoxins produced by *Anabaena* spp., *Oscillatoria* spp. and *Aphanizomenon flos-aquae* are responsible for animal poisonings around the world. Hepatotoxins ultimately lead to liver failure; symptoms in fish include flared gills (due to difficulty breathing) and weakness or inability to swim, which can result in mortality within 24 hours of exposure. Cyanobacterial hepatotoxins are produced by many genera of cyanobacteria, including *Microcystis*, *Anabaena*, *Planktothrix* and *Cylindrospermopsis*. Hepatotoxins have been implicated in deaths of fish, birds, wild animals, and agricultural livestock, and are responsible for human illness and death in India, China, Australia and Brazil.

Management of toxic cyanobacteria

Toxin production does not always occur in a bloom of toxin-producing cyanobacteria, but it is likely that toxins will quickly be produced in toxic amounts by high-density blooms of cyanobacteria. The decision to treat cyanobacteria with an algaecide is prompted by a variety of factors, including the size of the affected water resource, the number and type of organisms (e.g., fish, mammals) in the system, the age and condition of the organisms that will be potentially affected, the sensitivity of the target cyanobacterium to treatment, and the cost of treatment. Most toxin-producing cyanobacteria are susceptible to algaecide treatments, but some experimentation may be needed to identify the best treatment for a specific strain at a site. Occasionally, the idea that algal cells may leak toxins is proposed as a consideration for initiating – or choosing not to initiate – an algaecide treatment, but the idea that all algaecides cause toxin leakage in all situations is not supported by existing data. Also, algae can double their population densities in two to three days, and toxin production may be proportional to density, so choosing not to treat suggests that the risks associated with further production of toxin are acceptable. There is no way that treatment can increase the concentration of total toxin; however, failure to treat toxin-producing algae can result in increased exposure to toxins and associated risks. Management techniques other than algaecides may be considered as well. Tactics that have been tried include physical mixing and aeration, increasing flow rate or flushing to decrease hydraulic retention time, and decreasing or altering nutrient content and composition. Some of these options are site-dependent and therefore may or may not be viable, depending upon the site and situation.

Prymnesiophytes: the golden-brown algae

Most toxin-producing species in the genus *Pymnesium* form harmful blooms in brackish water, but strains are expanding into freshwaters, especially during droughts. Blooms of *P. parvum* have been responsible for mass mortalities of fish and significant economic losses in Europe, North America and other continents. Species of *Prymnesium* have spread to several freshwater systems in the US, possibly due to exceptional drought. Texas has been impacted with recurrent blooms in several reservoirs and rivers and Texas Parks and Wildlife has offered some detailed advice regarding management options (Sager et al. 2007).



Prymnesiophyte ecology

Prymnesium parvum is a relatively small (~10 microns), saltwater-loving organism that is commonly referred to as "golden algae." Golden algae are widely distributed and have been implicated in numerous and extensive fish kills in brackish waters and inland waters with relatively high mineral content on five continents. The species is capable of photosynthesis, but also feeds on bacteria and microorganisms. Dense growths of golden algae may color the water yellow to copper-brown or rust and the water may foam if aerated or agitated.

Prymnesium toxins

Golden algae produces at least three toxins, which alter cell membrane permeability and are collectively known as prymnesins. The toxin produced by *Premnesium* causes fish to behave erratically, and young fish are more sensitive than their elders. Affected fish may have blood in gills, fins and scales and they may be covered with mucus. Fish may move to the shallows of tainted waters and leap from the water in an attempt to escape exposure to the toxins. Gill repair can occur within hours if fish are moved to uncontaminated water during the early stages of intoxication, but moving affected fish to other systems may also spread golden algae to previously uninfected systems. Mammals and birds often eat dead fish and drink water in the area, but aquatic insects, birds and mammals are reportedly not affected by prymnesin toxins. The golden alga is not known to harm humans, but dead or dying fish should not be used for human consumption as a precautionary measure.

Management of toxic *Prymnesium*

Texas Parks and Wildlife has offered detailed advice regarding management options for *Prymnesium parvum* (Sager et al. 2007), but the reader is cautioned that some methods used to control algae in aquaculture and private pond settings may be illegal elsewhere. Control methods that have been used in isolated pond culture include treatment of *P. parvum* with ammonium sulfate and copper sulfate; however, the concentration of ammonium sulfate required to control *P. parvum* (~0.17 mg /L of unionized ammonia) may adversely affect some fish, and copper sulfate may kill desirable algae along with golden algae, thus decreasing food resources for zooplankton and disrupting fish feeding. In Chinese aquaculture of carp, suspended solids (mud), organic fertilizer (manure) and decreased salinity have been used to control *P. parvum* (Guo et al. 1996), with the best results from decreased salinity and ammonium sulfate. In addition, Rodgers et al. (2010) found that *Prymnesium* from several locations were controlled by 200 ug/L of chelated copper.

Euglenoids

Euglena is a genus of widely distributed algae found in many shallow, relatively calm, eutrophic freshwater systems throughout the US. Toxin-producing *Euglena* can cause fish mortalities in fresh waters; for example, a number of outbreaks of toxic *E. sanguinea* have occurred since 1991 in hybrid striped bass production ponds in North Carolina and have resulted in the loss of more than 20,000 pounds of fish due to complete kill in affected ponds.

Euglenoid toxins

Species of *Euglena* are sources of ichthyotoxin (a suspected neurotoxin) in freshwater aquaculture and have caused mortalities in striped bass, channel catfish, tilapia and sheepshead minnows. Symptoms of exposure to *Euglena* toxins begin with the fish going off its feed for no apparent reason. Within 24 hours of cessation of feeding, gills become reddened, fish swim at or near the surface in an agitated or disorientated state (often with the dorsal fin extending out of the water), swim on their sides, or even swim upside down. If steps are not taken immediately after observing this state, the fish will be dead within 24 hours.

Management of toxic *Euglena*

If a toxic *Euglena* bloom is suspected, do not aerate the pond, as this will disperse the bloom throughout the pond. Species of *Euglena* are exceptionally mobile, and as the toxicity event progresses to the point where exposed fish are disorientated, the highest concentration of toxins seems to occur in the downwind side of the pond. Euglenoids should be sensitive to several of the commercially available algaecides, particularly those with labels that specify that euglenoid algae are susceptible. In the past, species of *Euglena* have responded to treatments with chelated copper formulations at 0.12 – 0.5 mg/L, as well as to peroxide formulations at or below the maximum label rate.

Best management practices for noxious algae

As adaptive water resource management is practiced today, adhering to Best Management Practices for noxious algae involves the following:

1. Accurate diagnosis of the problem in a water resource, which requires representative samples of water or benthic material containing the potential noxious alga(e).
2. Identification of the targeted alga(e) and distribution by microscopic confirmation of the density or toxin or taste-and-odor compound production. Algae are not usually uniformly distributed in aquatic systems; they may be "layered" in the water column or blown by the wind, or may be in benthic patches.
3. Measurement of water characteristics for the site, which can influence algal growth as well as compatibility and performance of a treatment option (e.g., algaecide). The minimum data set needed typically includes temperature, pH, hardness, conductivity and alkalinity. Other information such as nutrient concentrations and suspended solids may be useful as well.
4. Site characteristics, which are important for discerning an appropriate and compatible approach based on water depth and area, as well as the designated uses for the water resource (e.g. drinking water supply, swimming, fishing, etc.). Site history such as previous use of algaecides and the frequency and intensity of noxious algal blooms would be useful.
5. Evaluation of potential options; as mentioned above, all options should be considered in terms of their compatibility with the site and situation, as well as their ability to achieve the desired outcomes. For example, a dye to block sunlight may be appropriate for a fountain or contained water body where the entire system can be treated, but may not very useful or efficient in systems where considerable water exchange occurs. As another example, NSF-certified algaecides may be required for drinking water resources.

6. Selection of an option or options, which may require some experimentation to select an appropriate option. Responses of target algae to algaecide exposures can differ due to formulation or application technique.
7. Application of the selected option to achieve the required exposure (often called "dose", "treatment" or "rate"), which is crucial to the success of a treatment [achieving the desired response from the target alga(e)]. The goal is to treat the target alga(e), not necessarily the water.
8. Monitoring results is an important step in adaptive water resource management that provides information to guide future decisions.

Summary

As more water resources are impacted by noxious algae and as these resources are increasingly utilized for critical purposes such as drinking water supply, irrigation and habitat for fish and wildlife, management of these crucial freshwater resources will become more prevalent. The need to constantly innovate and improve our approaches is clear and that is the goal of adaptive water resource management and BMPs.

NOTE: If an algaecide application is indicated, all regulatory approvals and permits must be obtained. Following label instructions and restrictions is necessary to comply with federal law. Mention of a control tactic for toxin-producing algae does not constitute endorsement of an algaecide or any other tactic for your specific situation. Check with your local extension agent regarding site-specific permit requirements and restrictions.

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•Sager D, L Fries, L Singhurst and G Southard (eds.). 2007. Guidelines for golden alga *Prymnesium parvum* management options for ponds and small reservoirs (public waters) in Texas. Texas Parks and Wildlife (Inland Fisheries): Austin, TX.

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Page 105: Floating mats of *Lyngbya wollei* at Kings Bay/Crystal River, FL; John Rodgers, Clemson University
Page 108: *Microcystis aeruginosa* along the shoreline of Pawnee Lake, NE; John Rodgers, Clemson University
Page 109: Photomicrograph of *Prymnesium parvum* from Dunkard Creek, WV; John Rodgers, Clemson University
Page 110: Photomicrograph of *Euglena sanguinea* from a pond in SC; John Rodgers, Clemson University
Page 111: *Euglena sanguinea* bloom on a pond in SC; John Rodgers, Clemson University

Chapter 15: Introduction to the Plant Monographs

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Eleven of the thirteen aquatic and wetland plants described in this chapter have one thing in common: they are of foreign origin. In addition, most were intentionally introduced to North America by humans. While native aquatic plants can sometimes become problematic, the plants in this chapter have caused significant economic and ecological damage to ecosystems throughout North America and will continue to do so for the foreseeable future. If you live in an area where none of these plants are found, you are among the fortunate few. You and your neighbors should make every effort to prevent the introduction and movement of these noxious weeds in your area.

The authors of the following plant descriptions have devoted years to researching the biology and control of these invasive species. Each weed species included in this chapter has distinct characteristics that cause it to be invasive and requires different techniques for control, but all authors agree on one concept – prevention is the most efficient and cost-effective method to protect natural areas from invasion by these noxious species.

A wealth of information is available on the internet about invasive species in general and the species described in this chapter. Excellent reference sources include local sites such as your state environmental protection agency and state invasive species working groups. National resources include the following websites:

•The United States Environmental Protection Agency: http://www.epa.gov/

•The University of Florida Aquatic Plant Information Retrieval System Online Database:
http://plants.ifas.ufl.edu/APIRS

•The University of Florida Center for Aquatic and Invasive Plants: http://plants.ifas.ufl.edu/

•USDA NRCS. The PLANTS Database. National Plant Data Center, Baton Rouge, LA:
http://www.plants.usda.gov/

•US Army Corps of Engineers Aquatic Plant Information System:
http://el.erdc.usace.army.mil/aqua/apis/apishelp.htm

Information and knowledge are the keys to prevention. Familiarize yourself with the characteristics of the invasive species described in this chapter so that you can positively identify them in the field. If you encounter a new population of one of these weeds, immediately notify the appropriate agency in your state and provide them with as much information as possible, including the location of the population. We are all responsible for the protection and stewardship of the ecosystem and your attention to detail can play a critical role in preventing the spread of these invasive species.

Chapter 15.1: Hydrilla

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Hydrilla verticillata (L.f.) Royle; submersed plant in the Hydrocharitaceae (frog's-bit) family
Derived from *hydr* (Greek: water) and *verticillus* (Latin: whorl) "water plant with whorls of leaves"

Introduced from Asia to Florida in the late 1950s
Present throughout the southeast and north to New England and Wisconsin; west to California, Washington and Idaho

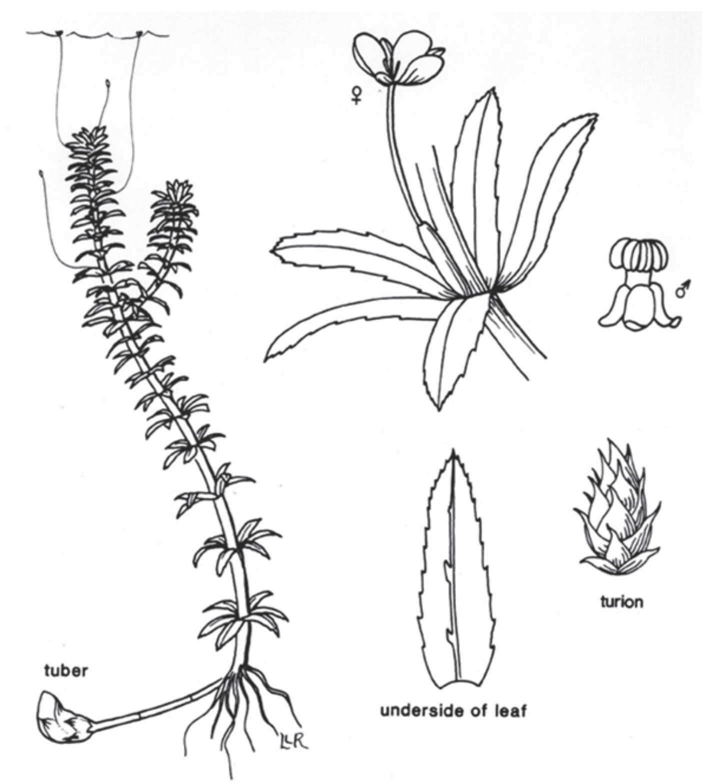
Introduction and spread

Hydrilla (*Hydrilla verticillata*) is the only species in the genus *Hydrilla* but several biotypes occur in its native range. Some biotypes are monoecious (each plant has both male and female flowers) and others are dioecious (each plant bears only male or female flowers). It appears that hydrilla was

introduced to North America on at least two separate occasions, which accounts for the distribution of two biotypes in the United States. The monoecious biotype was introduced most recently and may be the more cold-tolerant of the types. It was first discovered in the Potomac River in the late 1970s and can now be found in most areas north of Lake Gaston on the NC/VA border. The female-flowering dioecious biotype was introduced earlier and occurs exclusively in the southern United States from Florida to North Carolina and west to Texas. Dioecious hydrilla was introduced into Florida by the aquarium nursery trade in the 1950s and was spread rapidly throughout the state by intentional (plant growers) and unintentional (boat trailers) means. By the late 1970s hydrilla was included on the Federal Noxious Weeds List and a number of state prohibited plant lists as well. These listings have stopped the interstate sale and shipping of the species, but hydrilla is continually spread by irresponsible boaters and others who move plants from one watershed to another, since the species easily reproduces and forms new colonies from small plant fragments. There has been no direct evidence to suggest that hydrilla is spread by waterfowl and other aquatic fauna, but this type of transfer may occur between bodies of water that are in close proximity to one another. The introduction and spread of monoecious hydrilla in the northern US has not been well-documented because its appearance is very similar to that of the native elodea (*Elodea canadensis*). However, many confirmed initial infestations have occurred near public access points, suggesting that boaters continue to inadvertently transfer hydrilla on trailered boats.

Description of the species

Hydrilla is a rooted submersed perennial monocot that grows in all types of bodies of water, with its growth limited only by water depth and velocity of flow. The stems of hydrilla are slender (about 1/32″ in thickness), multi-branched and up to 25 feet in length – stems can grow as much as an inch per day. Hydrilla forms dense underwater stands and often "tops out" to form dense canopies or mats on the surface of the water. All vegetative parts of hydrilla are submersed and the appearance of the species can vary drastically depending on growth conditions such as water pH, hardness and clarity.



Hydrilla has small (to 5/8″ in length), strap-like, pointed leaves. The midrib on the underside of the leaf often has one or more sharp teeth along its length and leaf margins are distinctly saw-toothed, especially in hard water. Leaves are attached directly to the stem and are borne in whorls of four to eight around the stem, with a space of 1/8″ to 2″ between whorls. Healthy leaves are bright green, whereas leaves under stress from fungi, bacteria and sun-bleaching may be brown or yellow. Hydrilla is often confused with native elodea and exotic egeria or Brazilian elodea (Chapter 15.4). While these three species are very similar in appearance, leaves of native elodea are borne in whorls of three and those of egeria are arranged in whorls of four or five. In addition, only hydrilla has saw-toothed leaf margins; the leaf margins of the other species are smooth. It is often difficult – even for trained biologists – to tell hydrilla, native elodea and egeria apart. Plants can be positively identified as hydrilla by digging 1 to 2″ into the soil and looking for the presence of tubers or turions among the roots, as hydrilla is the only one of these species to produce these reproductive structures.

Reproduction

Dioecious hydrilla can only spread by vegetative means such as plant fragments because it does not produce seeds. Its spread by this method has been rapid and has increased the species' range throughout most of the southeastern US. Hydrilla produces two types of vegetative reproductive structures: turions and tubers. Turions are small (to 1/4″ in diameter), cylindrical, dark green and borne in leaf axils, whereas tubers are larger (to 1/2″ in diameter), potato-like, yellowish and attached to the tips of underground rhizomes 1 to 3″ below the surface of the sediment. Dioecious hydrilla produces tubers and turions during winter short-day conditions in the southeastern US, whereas monoecious hydrilla behaves like an annual and produces these structures in mid to late summer in northern waters. Hydrilla is the only species in the Hydrocharitaceae family to produce tubers and turions, so the presence of these structures is considered confirmation that the plant in question is indeed hydrilla. Underground tubers can remain dormant for many years; this protects the species from management efforts such as drawdowns (Chapter 6) and allows plants to survive adverse conditions. Studies have shown that a single sprouting tuber of dioecious hydrilla planted in shallow water can produce over 200 tubers per square foot each year.

The ecological importance of sexual reproduction in monoecious hydrilla (with both male and female flowers) is unknown. Flowers and seeds of hydrilla are tiny and therefore difficult to study in natural systems, but viable seeds have been produced under experimental conditions. Dioecious plants produce only female flowers and the lack of male flowers for pollination prevents seed formation. The female flowers of hydrilla are tiny (up to 1/16″ in length), white and borne singly on threadlike stalks. These stalks are attached to the stem in leaf axils near the tip of the stem and are up to 4″ in length, which allows the flowers to be level with the surface of the water. Male flowers are tiny, greenish and closely attached to leaf axils near the stem tips. When ripe, they separate from the stem and float to the surface, where they pollinate the female flowers by randomly bumping into them and dropping pollen into the female flower.

Problems associated with hydrilla

Hydrilla grows almost entirely underwater as a submersed aquatic plant and its growth potential is limited primarily by water clarity and depth of light penetration. Hydrilla has been reported at depths of 35 to 40 feet in crystal clear spring water and is commonly found at water depths of 15 to 20 feet in lakes with clear water. Hydrilla is uniquely adapted to grow under low light conditions, which allows it to colonize water that is deeper than most native submersed species can tolerate. For example, native submersed plants typically colonize the margins of shallow lakes where water depth is 6 to 8 feet. Hydrilla competes with native plants in these shallow areas, but also grows in much deeper water with no competition, which greatly extends the spread of the vegetated littoral zone outward from the shoreline.

Hydrilla infestations often go unnoticed until the species “tops out” and reaches the surface of the water, where it forms hundreds of lateral branches due to the increased light intensity. This surface canopy or mat formed in the upper 1 to 2 feet of water comprises as much as 80% of the biomass of the plant on an area basis and limits light availability to lower-growing native submersed plants, which reduces species diversity over time. The ecological effects of this dense growth on the water surface include significant changes in water temperature, wave action, oxygen production, pH and other parameters, which reduce the suitability of infested waterways for use by aquatic fauna. Human activities are adversely affected as well – recreational use of water is limited, property values are diminished and there are increased public health and safety concerns (e.g., mosquito control, drowning, flooding). The severity of problems caused by hydrilla depends on the characteristics of the infested water body. An acre or two of hydrilla in a 100-acre lake may cause few problems; however, coves, bays or lakes with infestations of 80% or greater are significantly impacted by hydrilla.

Management options

Clearly, preventing hydrilla from entering a water body is the best method to control this noxious species. Federal and state authorities have made it illegal to sell and transport hydrilla, which reduced this source of infestation. However, hydrilla still manages to increase its range and to colonize new bodies of water. Once hydrilla becomes established in a water body, control options are costly and generally must be employed on an annual basis.

Mechanical (Chapter 7) or physical (Chapter 6) control projects such as hand removal, benthic barriers or mechanical harvesters should be designed to prevent the spread of hydrilla fragments to other parts of the water body. Of course, if a lake is already extensively infested by hydrilla, there is less concern regarding plant fragmentation. Hand removal is labor-intensive and must take into consideration the presence of tubers and turions in and on the sediment, since failure to remove these structures virtually assures rapid reinfestation of the site. Mechanical harvesting can be expensive and most harvesters only cut to a water depth of 5 feet (although new deep-water harvesters have recently been developed – see page 49). Since hydrilla can grow an inch per day, control may only last for 2 months after mechanical harvesting. Another problem associated with mechanical harvesting is disposal of the harvested hydrilla. This vegetation has been evaluated for its potential as mulch, cattle feed, biofuel production and other uses, but its utility is very limited. Also, submersed plants do not produce much dry matter – a surface mat of hydrilla may weigh as much as 15 tons per acre, but contains only 5% (1,500 pounds) dry matter. As a result, harvested hydrilla is generally disposed of in a landfill due to its high water content (95% by weight) and low production of biomass.

Drawdowns and freezing of hydrilla tubers and turions may provide temporary control in northern locations, but these measures provide only a season or partial season of control in the southeastern

US. Thus, most hydrilla management programs rely on the use of biological control agents (grass carp) or herbicides.

Classical insect-based biocontrol of hydrilla has been studied for at least 30 years (Chapter 9). Researchers continue to seek possible biocontrol insects, pathogens and other agents in Asia and Africa. A few promising candidate insects have been discovered, studied and released to control hydrilla, but these insects have provided only localized and temporary reductions in hydrilla populations and are not considered to be viable biocontrol agents. In contrast, sterile triploid grass carp (Chapter 10) are widely used for hydrilla control in some states. Grass carp are released primarily in closed ponds or lakes and are sometimes used in conjunction with herbicides. Grass carp are not species-specific as required for the introduction of biocontrol insects; grass carp may prefer hydrilla but will consume most submersed and emergent aquatic plants. As a result, most states regulate the stocking and use of grass carp. Despite this challenge, grass carp continue to be the most effective method for biological control of hydrilla where their use is legal and practical.

Several herbicides can be used to effectively control hydrilla, but one of the most significant problems associated with chemical control of any submersed species is dilution (Chapter 11). An acre of water that is one foot deep comprises 325,800 gallons of water, which results in tremendous dilution of herbicides. In addition, water flow or movement greatly reduces the amount of time hydrilla is exposed to the herbicide. These factors can make it difficult to control hydrilla using chemical methods, so treatments should be designed to take dilution and water movement into consideration.

Fast-acting contact herbicides – including copper, diquat, endothall and flumioxazin formulations – are taken up quickly by hydrilla and result in rapid plant death and decay. These herbicides are generally used for spot treatments, strip treatments along shorelines and where water movement would limit use of slower-acting systemic herbicides.

Slow-acting systemic herbicides – including fluridone, imazamox, penoxsulam, bispyribac and topramezone – control hydrilla by inhibiting enzyme activity. These herbicides are usually applied as whole-lake treatments and provide control of hydrilla only when a long period of contact is possible. An advantage to systemic herbicides is that they are effective at low rates – usually concentrations of less than 100 ppb or even less than 20 ppb of fluridone, penoxsulam, bispyribac and topramezone. These herbicides slowly kill plants by starving them over a long period of time, but usually provide 1 to 2 years of control. Slow plant decay resulting from systemic herbicide treatments minimizes possible oxygen depletion and reduces the potential for fish mortality. The disadvantage of systemic herbicides is that they generally require a total lake treatment, or at least treatment in coves, bays and other areas where water movement and dilution are reduced and there is little or no water exchange. Most states require permits to apply herbicides in public (and some private) waters, so contact your state water authority for further advice and information.

Summary

Prior to 1950 there was no scientific information suggesting that hydrilla would cause such serious problems throughout the world. Hydrilla has become one of the world's worst submersed weeds as water resources have been developed and it now causes problems in all tropical and subtropical continents with the exception of Africa. Hydrilla has spread from Florida north to Maine and

Wisconsin and northwest to Washington in the span of only 50 years. The annual cost to control hydrilla in public waters in Florida alone totals approximately $15 million. Florida is particularly impacted by hydrilla due to its moderate climate and shallow, naturally nutrient-rich lakes, but research on the distribution of hydrilla in Asia predicts that hydrilla could colonize virtually any area in North America and could survive as far north as Hudson Bay.

For more information:

•Langeland KA. 1996. *Hydrilla verticillata* (L.f.) Royle (Hydrocharitaceae): the perfect aquatic weed. Castanea 61:293-304. http://plants.ifas.ufl.edu/node/184

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Photo and illustration credits:

Page 115: Hydrilla infestation; Vic Ramey, University of Florida Center for Aquatic and Invasive Plants
Page 116: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 117: Hydrilla bouquet; William Haller, University of Florida Center for Aquatic and Invasive Plants

Chapter 15.2: Eurasian Watermilfoil

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Myriophyllum spicatum L.; submersed plant in the Haloragaceae (watermilfoil) family
Derived from *myrios* (Greek: numberless), *phyllon* (Greek: leaf) and *spica* (Greek: spike) "plant with many leaf divisions that bears flowers in a spike"

Introduced to several locations in the US from Europe in the 1940s
Present throughout the continental US and Alaska

Introduction and spread

Eurasian watermilfoil (*Myriophyllum spicatum*) is one of fourteen species of *Myriophyllum* present in the US. Most species of this genus in the US are native, but two (*M. aquaticum* and *M. spicatum*) are exotic species that have been introduced to North America. Of these two exotic species, Eurasian watermilfoil is much more widespread and more problematic. The species was first reported in the US in the 1940s and spread rapidly into the mid-Atlantic and midwestern states in the 1960s and 1970s. Eurasian watermilfoil also became a serious problem in the hydropower and flood control reservoirs of the Tennessee River, where large-scale applications of herbicides were used in an attempt to eradicate the weed. Eurasian watermilfoil is still present in the TVA (Tennessee Valley Authority) system but has largely been displaced by hydrilla (Chapter 15.1). More recently (from the 1980s until 2009) the species has invaded lakes in Idaho, Minnesota and Maine and continues to expand its coverage throughout the northern US. Eurasian watermilfoil is now the most widespread submersed aquatic weed in the northern half of the US.

Eurasian watermilfoil has been introduced to the US multiple times and was likely first brought to North America in ship ballasts or as an ornamental plant for aquariums or water gardens. Accidental spread of Eurasian watermilfoil within the US is due primarily to transportation of contaminated boat trailers, boat parts and bait containers, but the species is also spread through the aquarium trade. Once Eurasian watermilfoil is introduced to a water system, it spreads prolifically by stem fragments that are produced both naturally (when stem sections detach from the plant at abscission sites) and as a result of mechanical breakage (when plants come into contact with boat motors and intense wave action). Some researchers speculate that Eurasian watermilfoil may be spread by wildlife or waterfowl; however, no direct evidence exists to support this theory. Eurasian watermilfoil produces numerous viable seeds, but the seeds contribute little to the propagation and spread of the plant. Eurasian watermilfoil was too widespread to be listed as a Federal Noxious Weed when the list was first developed; however, the species is listed on numerous state noxious and prohibited plant lists.

Description of the species

Eurasian watermilfoil is rooted in the sediment and grows completely underwater as a submersed plant that forms a dense canopy on the water surface. The species is commonly found in water from 1 to 15 feet in depth but can occur at depths of up to 30 feet if the water is extremely clear. Eurasian watermilfoil is an evergreen perennial plant that produces persistent green shoots throughout the year and overwinters as root crowns. Leaves are pinnately compound (feather-like), with each leaf composed of 14 to 24 pairs of leaflets arranged in whorls (groups) of four at the nodes of the stem. Stems and plant tips may appear reddish, but color is not consistent and may vary based on a number of factors, including environmental conditions. Flowers form on short aerial stems that hold them above the water and have both pollen-bearing ("male") and seed-producing ("female") flowers. Flowers are wind-pollinated and produce up to four nutlets per flower. Eurasian watermilfoil is difficult to identify and is often confused with several native species of *Myriophyllum*, including northern watermilfoil (*M. sibiricum*) and whorled watermilfoil (*M. verticillatum*). Hybridization between Eurasian and northern watermilfoils reportedly occurs in the field and the seedlings produced from these cross-pollinations often have features that are intermediate to the parental plants.

Reproduction

Eurasian watermilfoil produces a significant number of viable seeds and plants can be propagated from seed in the laboratory or greenhouse. However, successful colonization of new plants from seed in nature has not been documented. As a result, sexual propagation is generally thought to play an insignificant role in the spread of Eurasian watermilfoil. The species reproduces predominantly by vegetative means through fragmentation, which occurs when stems are broken mechanically (from wave action or contact with boat motors) and when stem sections naturally abscise or detach from the plant. Stem sections that result from natural breakage have high concentrations of starch and are likely responsible for most of the spread of the species. Eurasian watermilfoil can also spread by forming new root crowns on runners, which are produced when stems arch down, come into contact with the sediment and form roots that create a new root crown. Root crowns can also spread through the formation of rhizomes under the sediment, although detailed studies of this process have not been conducted. Root crowns overwinter and produce new shoots every year. As a result, more stems are added to root crowns each year, which increases stem density in the water column.

Problems associated with Eurasian watermilfoil

Because Eurasian watermilfoil grows entirely underwater as a submersed aquatic plant, the range of water depths the species can inhabit is limited by light penetration and water clarity. A dense canopy often forms at the surface of the water, which interferes with recreational uses of water such as boating, fishing and swimming. Dense growth of Eurasian watermilfoil may also obstruct commercial navigation, exacerbate flooding or clog hydropower turbines. In addition, excessive growth of the species may alter aquatic ecosystems by decreasing native plant and animal diversity and abundance and by affecting the predator/prey relationships of fish among littoral plants. A healthy lake is damaged because heavy infestations of Eurasian watermilfoil lower dissolved oxygen under the canopy, increase daily pH shifts, reduce water movement and wave action, increase sedimentation rates and reduce turbidity.

Management options

Prevention is always the best option to avoid infestations of Eurasian watermilfoil. Posting signs at boat launches and requesting that lake users watch for Eurasian watermilfoil and remove all plant material from boats before launching can be a successful strategy. When prevention methods are unsuccessful, early detection and rapid response to new infestations have been shown to reduce management costs over the long term.

There are currently no biological control agents that effectively control Eurasian watermilfoil. For example, grass carp (Chapter 10) do not feed on this species. Numerous studies have been conducted to evaluate the utility of native insect herbivores as potential biocontrol agents of Eurasian watermilfoil, but none have proven to be predictable and effective to date. Also, if native insects were able to effectively control introduced populations of Eurasian watermilfoil, new introductions of the weed would not result in population development and expansion to weedy proportions. Historical accounts of the introduction and spread of Eurasian watermilfoil suggest this has not occurred. In addition, the use of native insects as biocontrol agents remains controversial (Chapter 8).

Several herbicides can be used to effectively manage Eurasian watermilfoil. Contact herbicides – including diquat and endothall – provide good control, whereas systemic herbicides such as 2,4–D, fluridone and triclopyr provide excellent control. Herbicides should be selected based on site size and conditions, water exchange characteristics, potential water use restrictions, federal, state and local regulations and economic considerations (Chapter 11).

Mechanical controls (Chapter 7) are also widely used to control small infestations of Eurasian watermilfoil. Mechanical harvesting and raking provide temporary but fair control in bodies of water that are small to moderate in size, whereas hand harvesting and suction harvesting provide longer term control than mechanical harvesting or raking. None of these mechanical methods alone results in long-term control of Eurasian watermilfoil; as such, these methods should be employed as part of an integrated weed control strategy.

Physical control techniques such as drawdowns, dredging and bottom barriers (Chapter 6) can reduce or prevent growth of Eurasian watermilfoil by altering the environment. Drawdowns require dewatering of the affected lake or pond and are particularly effective during the winter. Draining the water out of the system exposes the root crowns of Eurasian watermilfoil to the air and results in desiccation and death of the plants. Dredging is expensive but results in water depths too great for plants to grow. Dredging provides multi-season control but should only be used as part of a broader lake restoration effort. Bottom barriers are semi-impermeable sheets of synthetic material that are placed over the plant bed, which kills the plants underneath. Bottom barriers are expensive but can provide effective control of Eurasian watermilfoil in small areas.

Summary

Eurasian watermilfoil is an exotic aquatic weed that is widely distributed throughout North America. The species is most commonly associated with problems in temperate lakes, but invades tidal estuaries, saline prairie lakes, rivers and southern reservoirs as well. Although the economic impact of Eurasian watermilfoil is not as great as that of hydrilla or waterhyacinth (Chapter 15.7), its geographic and ecological distribution surpasses that of other North American aquatic weeds. In fact, problems associated with Eurasian watermilfoil are significant enough that states such as Idaho, Minnesota, Vermont and Washington have developed specific management programs to control invasions of Eurasian watermilfoil.

For more information:

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Photo and illustration credits:

Page 121: Eurasian watermilfoil infestation; Ryan Wersal, Lonza Microbial Products
Page 122: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 123: Eurasian watermilfoil; John Madsen, Mississippi State University Geosystems Research Institute
Page 124: Eurasian watermilfoil; John Madsen, Mississippi State University Geosystems Research Institute

Chapter 15.3: Curlyleaf Pondweed

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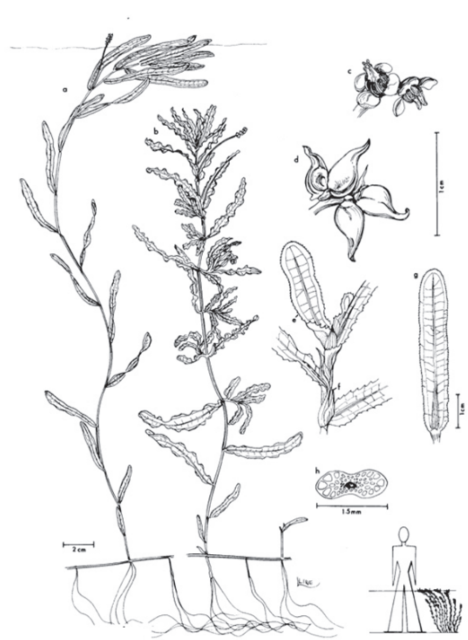
Potamogeton crispus L.; submersed aquatic plant in the Potamogetonaceae (pondweed) family
Derived from *potamos* (Greek: river), *geiton* (Greek: neighbor) and *crispus* (Latin: curly) "curly-leafed plant close to the river"

Introduced from Europe in the mid 1800s
Present in all lower 48 states; particularly problematic in northern states and Canada

Introduction and spread

Native to Europe, Asia, Africa and Australia, the first known collection of curlyleaf pondweed in North America occurred in Philadelphia in 1841. The plant spread to the Great Lakes region in the early 1900s and today is found in all of the contiguous 48 states. The spread of curlyleaf pondweed throughout the US can be attributed to boat and fish hatchery activity. Curlyleaf pondweed is now thoroughly naturalized in the United States and Canada and is considered an exotic weedy species throughout its range.

Description of the species



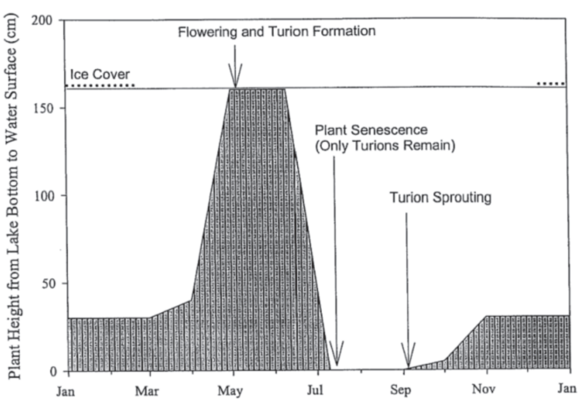
Curlyleaf pondweed is a rooted submersed herbaceous perennial monocot that grows in lake and river systems and aggressively outcompetes native submersed vegetation. The species has wavy leaves with finely serrated or toothed margins and a "crisp" leaf texture. Leaves are typically green early in the season and can become red when they near the water's surface. The oblong-shaped leaves are 1 to 3" in length and are attached to the stem in an alternate arrangement. Long spaghetti-like stems form as the plant quickly grows to the water's surface and develops into dense weedy mats.

Curlyleaf pondweed grows in conditions ranging from ice-covered waters with very low light intensities to summer conditions with very warm temperatures and intense sunlight. Colonization by curlyleaf pondweed is limited by light availability and the species typically inhabits waters that range from 3 to 6 feet in depth, but curlyleaf pondweed has been found at depths of more than 20 feet in very clear water. This species prefers to grow in still water, but curlyleaf pondweed is quite tolerant of flow and is found in many river systems throughout the US and Canada.

Curlyleaf pondweed is often found in nutrient-rich or eutrophic systems and the species has a high tolerance for nutrient pollution and low light conditions. In fact, the species is sometimes considered an indicator of pollution and eutrophication due to its tolerance of low light and high dissolved nutrients.

Reproduction

Curlyleaf pondweed reproduces primarily by producing turions and rhizomes. Turions are hardened modified reproductive buds that form from apical buds, in leaf axils or directly from rhizomes prior to plant senescence in early summer. A single plant produces an average of 5 turions, with each turion averaging 4 buds. Turions constitute over 40% of the total plant biomass prior to senescence and turion densities of more than 1,000 per square foot have been reported in lake sediments. Each turion can remain viable in the sediment for multiple seasons and can sprout multiple times. Flowering usually coincides with turion formation. Flowers are very small, inconspicuous and borne on small spikes that emerge above the water surface. Seeds are produced but germination rates are quite low (0.5%). As a result, reproduction of curlyleaf pondweed is due mainly to the production and sprouting of vegetative turions.



Curlyleaf pondweed has a life cycle that is fairly unique for submersed aquatic plants. Plants flower and produce turions, then die back or senesce, typically in early summer. Turions lie dormant throughout the summer and then sprout in the fall when water temperatures drop to below 66 °F and daylength shortens to fewer than 11 hours of daylight. Plants grow and can reach from an inch to several feet in height until water temperatures fall below 50 °F. When temperatures drop below 50 °F, growth of curlyleaf pondweed slows or stops and plants overwinter in a very slow-growing or dormant state. Since the species overwinters with green growth above the sediment, curlyleaf pondweed often has an advantage over native species when growth resumes in the spring.

Curlyleaf pondweed can grow up to 4” per day when days become longer and water temperatures start to rise in early spring. Plants quickly grow to the surface and turion production and flowering begin. Dense mats of curlyleaf pondweed also form on the water surface and shade out competing species. Turion production and flowering are followed by senescence or dieback, which occurs by the 4th of July in many areas.

Problems associated with curlyleaf pondweed

Curlyleaf pondweed forms dense mats on the water’s surface in May and June, which inhibits fishing, boating and other types of water recreation. Dense growth of curlyleaf pondweed in moving water systems can obstruct flow and can exacerbate flooding due to large amounts of biomass obstructing river channels. Dense surface mats of plant material also limit light to low-growing submersed native species; in fact, monocultures of curlyleaf pondweed often result from this competition for light. Dense vegetation at the water's surface also can stagnate the water column and inhibit oxygen exchange from the surface to the lake bottom. Decomposing plant material under the weedy canopy further reduces dissolved oxygen levels in the water column. These conditions can reduce or eliminate fish and aquatic invertebrates in dense beds of curlyleaf pondweed. Mosquitoes, on the other hand, find curlyleaf pondweed beds to be the ideal habitat.

Curlyleaf pondweed typically senesces when water temperatures rise and dissolved oxygen levels begin to decline. The large amount of decomposing biomass produced from senescence releases nutrients and decreases oxygen in the water column, which further stresses the aquatic community. Algal blooms commonly occur after senescence of curlyleaf pondweed and decreased water clarity and oxygen levels can persist for the entire summer season.

Management options

Curlyleaf pondweed often requires management in order to preserve the recreational and environmental value of the bodies of water infested by the species. The most effective and efficient way to protect waterbodies from curlyleaf pondweed and other invasive aquatic species is prevention. Curlyleaf pondweed is on a number of state noxious weed lists, which make it illegal to sell or transport the species. The best way to prevent the introduction of curlyleaf pondweed into new waterbodies is to ensure that all plant material is removed from boats and trailers. Boats, trailers and gear should be thoroughly inspected, washed (with hot water) and dried before moving to a different water body to prevent the spread of curlyleaf pondweed and other invasive aquatic species.

There are a number of options for control and management in bodies of water that are already infested with curlyleaf pondweed. Physical (Chapter 6) or mechanical (Chapter 7) control options include hand removal, benthic barriers and mechanical harvesting. Hand removal by raking or hand pulling using divers can be effective tools for controlling plants in localized areas, but these efforts can be costly and time-intensive. The turion bank in the sediment should also be considered with hand removal, since regrowth from turions can quickly reinfest cleared areas. Curlyleaf pondweed can also be spread by fragments, so measures should be taken to prevent fragments and turions from spreading. Benthic barriers are effective for curlyleaf pondweed control in localized areas. The barriers prevent regrowth from turions in the sediment and, if barriers are maintained, can provide long-term control. However, benthic barriers are labor-intensive to install and maintain and often require installation permits. Mechanical harvesting can provide temporary control of curlyleaf pondweed, but can also exacerbate the spread of fragments and turions. Management programs can include mechanical harvesting to improve boater and recreation access by effectively “mowing the lawn” to remove nuisance growth, but disposal of harvested biomass can be problematic due to the large volumes of heavy plant material. Drawdown of a body of water is an effective method for seasonal control of curlyleaf pondweed. However, drawn-down areas of shoreline can quickly be reinfested by curlyleaf pondweed plants in deeper water and by sprouting of turions in the sediment. Also, drawdowns are non-specific and will likely damage populations of desirable native submersed plants as well.

There are currently no known insect or pathogen biocontrol agents that attack curlyleaf pondweed, but sterile triploid grass carp (Chapter 10) can provide control of the species. However, grass carp are non-specific herbivores that will eat many native plant species. Grass carp are also illegal in many states and can typically be used only in closed systems.

Several aquatic herbicides – including diquat, endothall, flumioxazin, fluridone, penoxsulam, bispyribac and imazamox – can be used to effectively control curlyleaf pondweed. Diquat, endothall and flumioxazin are contact herbicides and are relatively fast-acting, whereas the other herbicides are systemic products that are often used as whole-lake treatments and require longer contact times for control (Chapter 11). Research has shown that early season treatments with herbicides can very effectively control curlyleaf pondweed and prevent turion production. Most native plant species are still dormant early in the spring, so treatment at this time prevents damage to many desirable native plants while providing selective control of curlyleaf pondweed. Since effective control early in the season prevents turion production, regrowth of curlyleaf pondweed is reduced the following year.

Summary

Curlyleaf pondweed is a problematic invasive submersed aquatic weed in the northern US and in Canada. The species grows and reproduces at very high rates and can quickly cover the entire surface of a body of water with dense monocultural growth. Dense growth of curlyleaf pondweed impedes recreation, reduces populations of native submersed plant species and alters the ecosystem so that it is inhospitable to fish and other fauna. Active management is often required to maintain the environmental and recreational value of water bodies infested with curlyleaf pondweed.

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Page 127: Curlyleaf pondweed; Thomas Woolf, Idaho State Department of Agriculture

Chapter 15.4: Egeria

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Egeria densa Planch.; submersed plant in the Hydrocharitaceae (frog's-bit) family
Derived from *Egeria* (Greek: water nymph) and *densa* (Latin: dense) "densely growing water plant"

Introduced from South America to the northeastern US in the 1890s
Present throughout most of the US except Arizona and the upper Midwestern states

Introduction and spread

Egeria (*Egeria densa*), sometimes inappropriately referred to as *Elodea densa*, is easily confused with nonnative hydrilla (Chapter 15.1) and native *Elodea canadensis*. Physical similarities among the three species are responsible for the confusion in proper identification and, by extension,

inconsistent naming. The popularity of egeria in home aquariums and ponds and its frequent use in biology classrooms are likely responsible for the widespread distribution of egeria across the US and elsewhere. Egeria has many common names (including anacharis and Brazilian elodea) and is commonly referred to as "oxygen weed" on many internet sites, where the species is touted for its ease of growth and ability to increase dissolved oxygen in freshwater aquariums and ponds. Many aquarists fail to consider the downsides of the plant's rapid growth rate and its effect on early-morning dissolved oxygen levels.

Plants release oxygen during the day; however, plants respire (take up oxygen) at night and cause the lowest oxygen levels to occur in the early morning. Fish kills can occur if plant density is high enough and dissolved oxygen levels become depleted overnight due to plant respiration. Like many aquatic weeds, egeria was most likely brought to the US through the aquarium trade and the species was probably first introduced to natural waterways as a result of aquarium dumping and flooding of ornamental ponds. Some states now list *Egeria densa* as a noxious weed, which may slow commercial sales and introduction to new waterbodies. The current spread of egeria is due primarily to recreational activities such as boating, fishing and the use of personal watercraft. Similar to hydrilla, initial infestations of egeria are often found near public boat ramps, providing further evidence for this means of spread.

Description of the species

Egeria is a rooted submersed monocot that grows in a variety of fresh water bodies, including flowing and standing water. Growth of egeria is limited when the species is exposed to extremely warm (above around 90 °F) or cold (below around 40 °F) water for several weeks; however, egeria can withstand low light and low temperatures similar to Eurasian watermilfoil (Chapter 15.2). The species' limited tolerance for high water temperatures may explain the shift in species dominance from egeria to hydrilla during the summer in some Florida water bodies. Egeria has stems that are highly branched and can reach lengths of 25 feet or more due to the species' tolerance of very low light levels. The long stems from a single rooted plant commonly form a canopy near the water surface that can cover an area of six feet or more, a growth habit that is observed in other canopy-forming submersed weeds. Leaves of egeria are thin, small (1-1/2" long and 1/8" wide), lance-shaped and have minute teeth along the edges that may be difficult to see without a magnifying glass. Leaves are arranged in whorls around the stem, with each composed of four to six leaves per whorl. Leaf nodes are so densely spaced at the growing tip of the plant that they are indistinguishable, but nodes are more widely spaced near the main stem and on stems lower in the water column. Branches are borne from distinct and rather predictable locations along the stems of egeria. The number of leaves per whorl doubles or even triples (up to 12 leaves per whorl) every 8 to 12 leaf nodes, which has led some to

refer to these unique regions as "double nodes." These double nodes are the only location where branches and flowers are borne along the stems.

Reproduction

Egeria is dioecious, meaning that plants bear only staminate (male) or pistillate (female) flowers. "Female" plants (with pistillate flowers) are not known to occur outside South America. In rare cases these plants are found, but sexual reproduction and seed set are extremely rare. This has resulted in widespread distribution in the US of "male" plants (with staminate flowers) which likely have little genetic variation. Egeria spreads exclusively from vegetative propagules including stems, branches and root crowns. Branches, roots, flowers and root crowns are formed along plant stems adjacent to

double leaf nodes every 8 to 12 leaf whorls. Unlike several other invasive submersed plants, egeria does not produce tubers, turions or rhizomes to facilitate spread or to provide energy storage for overwintering. Instead, egeria relies on stems and root crowns for colonization and survival during inclement conditions. Closely spaced double nodes in stem tips result in the greatest potential for growth in this region, which can make management of the species difficult. Egeria can produce a new plant from each double node along a stem fragment; this, coupled with its rapid growth rate (easily growing up to 1/2" per day), allows for the rapid expansion and competitive ability of the species.

Problems associated with egeria

Egeria roots in the sediment at the bottom of the water body and grows completely underwater but forms a dense mat just under the water surface. The result is a thick canopy of vegetation that spreads over large areas and impacts recreation, property values, water quality and ecosystem function.

Dense growth of egeria entangles boat propellers and impedes navigation, which often results in the unintended spread of the species when stem fragments are created after a close encounter with a boat prop. Fragments can float for days or weeks before sinking into the sediment or being stranded along shorelines. These fragments quickly form roots, which results in new colonizations or substantial increases in plant bed size that would not occur naturally. Because egeria is largely transported by human activities, infestations tend to occur near boat launches, adjacent swimming areas, marinas and boat docks. Thick mats of surface vegetation in these areas are extremely unsightly and even dangerous for users of these facilities.

Water quality may be compromised by thick surface growth of egeria. Dense growth reduces the natural mixing of water by wind and causes an increase in surface water temperature during the summer, which is harmful to fish and invertebrates. Thick mats also provide a protected growth platform for filamentous algae that are unsightly, cause odors upon decay and can spawn large mosquito populations. Reduced wind mixing also restricts the entry of atmospheric gases (i.e., oxygen and carbon dioxide) to the water. Oxygen is necessary for fish and invertebrates, while carbon dioxide is necessary for growth of submersed plants, including algae. As with hydrilla, dense growth of egeria also causes wide daily fluctuations in pH and other water quality parameters, which makes infested waterways inhospitable to many aquatic animals.

Management options

Egeria has been sold as an aquarium plant in the US for as many as 50 years, but it has not spread through the country as quickly as other noxious species such as hydrilla. The first lines of defense to reduce the impacts of egeria are to prevent the introduction of the species to new water bodies and to limit its spread in waters that are already infested. The most efficient and effective preventative measure is to thoroughly remove plant fragments from boat trailers and watercraft before leaving an infested waterbody. In fact, removing all aquatic vegetation reduces the likelihood of spreading other nonnative species such as zebra mussels and other inconspicuous species. The cost of prevention (e.g., through signage, boat inspections, boat washing stations, etc.) is orders of magnitude less than the cost of managing existing populations because once egeria is established it is extremely difficult, and most would argue impossible, to eradicate.

Physical (Chapter 6) and mechanical (Chapter 7) controls for egeria are similar to those for other submersed weeds, largely due to their ability to establish new colonies from stem fragments. As a result, the benefits and drawbacks of various control methods are similar among the species. Hand removal and the use of benthic barriers can be selective; however, these methods are very laborious and time-intensive. Because egeria does not produce tubers or turions, the likelihood of reinfestation after benthic barriers are removed or when hand pulling is completed is reduced, provided both methods are employed with vigilance. Mechanical harvesters can clear large areas for boat navigation; however, harvesters can produce thousands of fragments that can expand the population. Since harvesters essentially mow the upper portions of the plant, the need to remove stem tips after mechanical harvesting cannot be understated; otherwise, stem tips float away and spread the plant to new habitats within a water body. In addition, multiple harvests are usually required during the peak growing season due to the rapid growth rate of egeria.

Water level drawdowns may be used where feasible to control egeria in regulated water bodies (e.g., irrigation canals and reservoirs for power generation or flood control). Duke Power Company has used drawdowns for many years to control egeria in power station reservoirs in the Carolinas and Virginia. Egeria may be the submersed aquatic weed most susceptible to drawdown and desiccation because seeds, tubers or turions are not produced to allow for re-growth; as a result, drawdown can provide control for 2 to 3 years. Plants are particularly vulnerable during winter drawdowns when dry and freezing conditions are present. The required duration of dewatering depends on various climatic and sediment conditions such as relative humidity, temperature and sediment density (the ability of soil to retain water). Disadvantages to drawdown include lack of specificity (nontarget native plants and wildlife are impacted) and loss of the water for other purposes such as hydropower, irrigation and recreation.

Although research is currently underway to identify effective and safe biocontrol agents, the only biocontrol agent currently available for reducing egeria biomass is the sterile grass carp (Chapter 10). Grass carp have been stocked following drawdown in some locations, which has led to long-term control. Sterile grass carp effectively control egeria in areas where low water temperature does not limit their feeding; unfortunately, egeria is capable of positive and sustained growth in climates cooler than those required for active grass carp feeding, so effectiveness may be limited under those conditions.

Herbicides commonly used to control egeria include the systemic herbicide fluridone and the contact herbicides copper and diquat (Chapter 11). The list of herbicides that can be used to effectively control egeria is very limited compared to those used to control Eurasian watermilfoil. Egeria is a monocot and is therefore not susceptible to 2,4–D or triclopyr. Endothall effectively controls hydrilla, a species that is closely related to egeria; however, endothall has no effect on egeria. Egeria is often found in systems with flowing water, which makes the use of slow-acting systemic herbicides challenging because plants require a long exposure time in order for systemic herbicides to provide effective control. The growth of egeria in flowing water systems coupled with a limited number of effective herbicides make egeria a difficult plant to control with herbicides.

Summary

The popularity of egeria in the aquarium trade and in biology classrooms has substantially contributed to its widespread distribution in the US, Europe, Asia, New Zealand, Japan, Chile, Mexico, Canada and Australia. The spread of egeria between water bodies is largely due to trailered boats and other watercraft that transport fragments. Long-lived stem fragments are easily spread by currents and watercraft within infested water bodies. When these fragments come into contact with sediments on the lake bottom or the margins of the water, the fragments form roots, plantlets develop and new colonies of egeria rapidly become established. Egeria tolerates a wide range of water quality characteristics, sediment nutrient levels and light levels and commonly grows in similar habitats favorable to Eurasian watermilfoil. As a result, it is likely that egeria can invade and colonize areas that currently support growth of Eurasian watermilfoil.

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Page 130: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 131: Egeria; Toni Pennington, Tetra Tech, Inc.
Page 132: Egeria; Toni Pennington, Tetra Tech, Inc.

Chapter 15.5: Fanwort and Cabomba

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Cabomba caroliniana A. Gray; submersed plant in the Cabombaceae (watershield) family. Derived from *Cabomba* (an aboriginal name per botanist Asa Gray in 1848) and *caroliniana* (having a range that includes North and South Carolina in the US)

Native to the southern US, although some "populations" appear introduced from the aquarium industry. Found in the southeast, northeast, midwest and Pacific northwest US

Introduction and spread

Fanwort (*Cabomba caroliniana*) is one of five species of the genus *Cabomba* and the only one broadly distributed in the United States (although *C. haynesii* and *C. palaeformis*, both known by the common name fishgrass, reportedly occur in Miami-Dade County in extreme southern Florida). There are three varieties of fanwort, but only two (*C. caroliniana* var. *caroliniana* and var. *pulcherrima*) are considered native to the US. In addition to native populations of fanwort found throughout most of the eastern US, there is also a new type of fanwort that was likely introduced via the aquarium trade. Members of the genus *Cabomba* appear very similar to one another and are difficult to identify with certainty; even plant taxonomists are currently unable to clearly define species and subspecies of *Cabomba*. However, it is clear that many of the new populations of *Cabomba* found throughout the midwestern US and Canada are invasive and have other characteristics that distinguish them from native populations. These invasive types will hereafter be referred to as "green cabomba"; the term "fanwort" will refer to members of the species *C. caroliniana*.

There is little information outlining the introduction of green cabomba, but research in the early 1980s revealed that the aquarium trade had discovered or developed a variety of fanwort that was solid (or nearly solid) green. Populations of green cabomba began to appear and rapidly expand in the midwestern and northwestern US, Canada and Australia in the early 1990s. Because these populations are similar in appearance and invasiveness, it seems likely that they were introduced from a common source – probably the aquarium trade. In addition to these new invasions of green cabomba, invasive behavior has also increased in native populations of fanwort in the southeastern and northeastern US.

Description of the species

Fanwort is a perennial dicotyledonous plant that roots in the sediment and grows entirely submersed in the water column. It colonizes new areas through prolific root growth or through shoot fragments that become rooted in the sediment. The species typically grows in shallow waters, but can be found at depths of up to 30 feet if the water is clear. Abundant branching occurs at the root crowns and base of the plant. Shoots grow to the surface of the water and continue to elongate, producing thick mat-forming canopies. Stems are round to slightly compressed and range in color from green to red (although stems are always green in green cabomba). Submersed leaves are opposite, fan-shaped, finely divided with as many as 200 terminal points on a single leaf and range from green to red. Leaves can vary greatly in size, but leaves near the tip of the plant are usually smaller and closer together than lower leaves.

Flowering occurs on the surface of the water on branches with floating leaves. Floating leaves look very different from submersed leaves and are alternate, smooth and linear-elliptic to ovate. Flowering stems bear single bisexual white flowers with 3 petal-like sepals and 3 petals; some flowers have yellow spots or purplish margins. Populations of native fanwort flower profusely, but green cabomba produces few flowers.

Fanwort prefers to grow in acidic water with a pH of 4 to 6 and growth is inhibited when water pH is above 7. Green cabomba, however, can survive in water with a higher pH and growth is not affected unless pH is 8 or higher. Fanwort is considered a more tropical species and proliferates in the southeastern US, whereas invasive green cabomba has colonized the much colder climates of the midwestern US and Canada and has adapted to overwinter there. During late fall when temperatures begin to drop, green cabomba stems break off and turion-like structures form at the apical tip. When warmer temperatures return in early spring, these fragments will begin to elongate and form adventitious roots.

Variations in color are the most significant barrier to separating members of the genus *Cabomba*. Most descriptions of fanwort list color as ranging from green to red, with red coloration most common in warmer temperatures and green in cooler temperatures. True fanworts – for our purposes, *Cabomba caroliniana* – do often have green leaves close to the base of the plant and red to purple leaves near the tip of the plant, but this is highly variable. Some populations may be entirely red to purple with no green (these plants are most likely *C. caroliniana* var. *pulcherrima*); however, other plants may appear red to purple but have green leaves in deeper water. In contrast, green cabomba is always entirely green and water temperature has no effect on color. These color differences provide some evidence to support the theory that green cabomba is unique from native fanworts, but there are differences in physiological responses as well. For example, research has shown that green cabomba grows more quickly, tolerates cold temperatures, survives under a wider range of water pHs and may be more tolerant of some herbicides than native fanworts.

Reproduction

Fanwort and green cabomba reproduce using multiple strategies. Both spread via vegetative fragmentation; a single leaf node can produce roots and grow into a new plant. As such, contaminated watercrafts, trailers and live wells can transfer these species to new areas. Also, both species grow in slow flowing canals and rivers, so plant fragments can travel long distances on currents until they settle in a suitable habitat. Fanwort spreads primarily through vegetative fragmentation, but sexual reproduction does occur. Flowers are usually pollinated by insects, although self-pollination can occur as a result of wave action. Flowering is a two-day event; flowers emerge and can be pollinated on the first day and are closed and pulled below the surface of the water for seed formation on the second day. Seed viability is very low in fanwort, but whether green cabomba produces viable seeds is unknown.

Problems associated with fanwort and cabomba

Species of *Cabomba* produce mat-forming canopies that can become quite dense, particularly when these mats are made by green cabomba. Dense canopies decrease light penetration through the water column, which can displace or eliminate other desirable or native plant species (Chapter 1), thus creating a monoculture of fanwort or green cabomba. This lack of diversity can impact fisheries (Chapter 2) and waterfowl (Chapter 3), especially when coupled with the reduced dissolved oxygen levels that result from poor penetration of oxygen through dense vegetation. These thick mats can also impede navigation and recreational use of the water body and can have negative economic impacts on the industries that utilize these resources. Plant fragments may also clog drainage pipes, canals, intakes, pumps and other structures, which can impede irrigation, drainage and flood control efforts.

Management options

Mechanical control (Chapter 7) is unlikely to be successful in eradicating fanwort and green cabomba from an aquatic system, since harvesting can produce fragments that can root, form new plants and quickly recolonize the water body. Also, extensive root systems are often undisturbed by harvesting and new plant growth from these roots can quickly re-infest an area after harvesting operations are concluded. Drawdowns (Chapter 6) can be used to control fanwort and green cabomba, but are not practical in areas where the waters are heavily utilized for recreational activities and elimination of the resource is not an option. Because fanwort grows best in low-pH water and is inhibited at higher pH, it may be possible to use lime as a control strategy. The addition of lime to the water will raise pH and create an unsuitable environment for fanwort. However, this is practical in smaller bodies of water and is likely to drastically alter the ecosystem in these waters. There are no known biological control agents (Chapter 8) for fanwort, although the generalist herbivore grass carp (Chapter 10) will provide some control of the species. Because green cabomba was probably created by the aquarium industry, it is unlikely that biocontrol agents will be identified for green cabomba, since these agents would also likely feed on native fanworts.

Chemical control (Chapter 11) of fanwort is possible with several herbicides, but control of green cabomba is much more challenging. Contact herbicides such as diquat, endothall (amine salt) and flumioxazin, along with the systemic herbicide fluridone, can be used to control fanwort. Diquat and fluridone have little effect on green cabomba, but flumioxazin seems to be effective. High rates of the amine salt of endothall can also reduce biomass, but toxicity to fish is a concern when using high rates of endothall amine. Thus, options for chemical control of *Cabomba* species – particularly green cabomba – is limited at this time.

Summary

Although fanwort is a native species, populations of green cabomba behave like – and have impacts similar to – an invasive species. Native populations of fanwort are prevalent in the southeastern US, whereas green cabomba is more common in Canada and in the midwestern, northeastern and northwestern US. Identifying species in the genus *Cabomba* is challenging, which makes it difficult to characterize invasions by green cabomba; however, it is clear that its rapid spread to new areas of the US over the last few decades is troubling. Furthermore, the rapid spread of green cabomba through fragmentation and a lack of available management tools is cause for concern, as it may be difficult to limit the spread and impact of this plant throughout the US.

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Page 136 upper: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 136 lower: Color variation in cabomba/fanwort; Brett Bultemeier, Clarke Aquatic Services
Page 137: Cabomba flower; Lyn Gettys, University of Florida
Page 138: Cabomba population; Lyn Gettys, University of Florida

Chapter 15.6: Waterchestnut

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Trapa natans L; floating-leaved plant in the Trapaceae (waterchestnut) family; originally placed in the Hydrocharitaceae (frog's-bit) family; sometimes placed in the Lythraceae (purple loosestrife) family
Derived from *calcitrapa* [Latin: a spiked iron ball ("caltrops") used as an ancient weapon] and *natans* (Latin: swimming)

Introduced from Asia to Massachusetts and New York in the late 1870s to early 1880s
Present in the mid-Atlantic into the Northeast, south to northern Virginia, west to central Pennsylvania, east to New Hampshire, north to Quebec

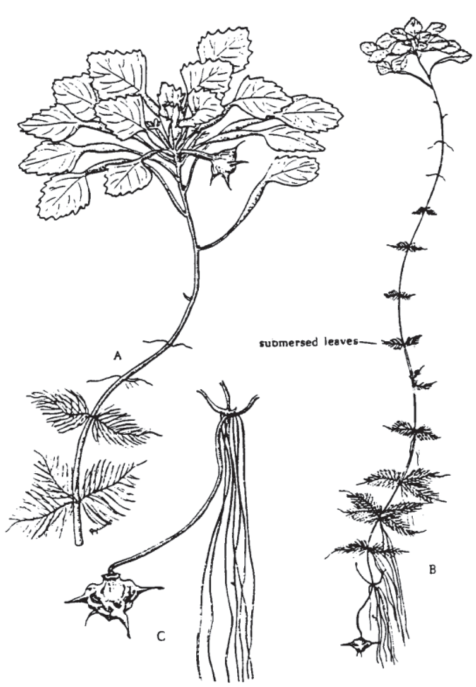
Introduction and spread

Some botanists have subdivided the genus *Trapa* into more than 25 different species based upon small differences in the nutlets. Under the most recent taxonomic schemes, *Trapa natans* is subdivided into three varieties. The varieties *Trapa natans* var. *bispinosa* and *Trapa natans* var.

bicornis are found primarily in northern India and southeastern Asia, where both are grown as agricultural crops, whereas the variety *Trapa natans* var. *natans*, commonly called waterchestnut, is a prized agricultural crop in India and China, a protected and disappearing plant in Europe and a highly aggressive invader in the United States. Waterchestnut is often confused with the Chinese waterchestnut (*Eleocharis dulcis*), an edible tuber common in Chinese cuisine. Both species have been widely cultivated as a food source, but they are unrelated. Although "waterchestnut" is the most widely used common name for *Trapa natans* var. *natans*, the variety is also known by a number of other common names, with religious ("Jesuit's nut"), evocative ("water caltrops") and sinister ("devils nut", "death flower") connotations.

Waterchestnut is native to Eurasia and Africa and archaeologists have found evidence of waterchestnut in sediments dating back to at least 2800 BC. The first introduction of waterchestnut to the US is better documented than that of most other exotic plants, but there is some debate regarding the specific time and place of this introduction. The initial introduction to North America was well-described by Eric Kiviat in a Hudsonia newsletter. North American infestations can probably be traced to two distinct locations. Waterchestnut was first introduced from Europe to Middlesex County, Massachusetts around 1874 and was cultivated as an ornamental in Asa Gray's botanical garden at Harvard University in 1877. Seeds were distributed by Harvard gardeners into nearby ponds over the next several years; as a result, waterchestnut migrated into the Concord and Sudbury Rivers by the mid 1880s, reached nuisance portions by the turn of the century and underwent explosive growth by the 1940s.

Another introduction occurred in Scotia in eastern New York during the early 1880s. A Catholic priest planted waterchestnut seeds from Europe in Sanders Pond (now Collins Lake), which led to extensive colonization of the lake by 1884. Subsequent flooding of the neighboring Mohawk River (via locks and dams on the New York Barge Canal) further spread the plant and spawned widespread growth by the 1920s. Waterchestnut was reported in the Hudson River by 1930 and reached nuisance levels in the 1950s. The species likely then spread west through the Erie Barge Canal system and reached Oneida Lake and the Finger Lakes region by the turn of the 21st century. Waterchestnut also migrated north into Lake Champlain through the Hudson-Champlain Canal and most likely reached Quebec through the Richelieu River system during the late 1990s. Waterchestnut was first found in Maryland in the late 1910s and reached the Potomac River during the early 1920s; widespread populations were present by the 1940s.



Description of the species

Waterchestnut is an ideal candidate for early detection programs because its appearance differs from all other plants found in North America and the species can often be identified early in its colonization cycle. Waterchestnut is an annual floating-leaved dicot that grows primarily in sluggish, shallow water. The habitat for this species includes lakes, ponds, reservoirs, sheltered margins of flowing water, freshwater wetlands and fresh to brackish estuaries. Waterchestnut usually grows in water less than 7 feet deep but has been found at depths of 12 to 15 feet. The species prefers thick, nutrient-rich organic sediments and an alkaline environment, but is tolerant of a wide pH range. Waterchestnut will not grow in salt water, although it can survive in brackish water with freshwater springs and groundwater input. The species grows aggressively and regularly produces as much as one pound of dry weight per square yard of surface area. Severe infestations can result in much greater biomass production; for example, waterchestnut populations growing in shallow impoundments in upstate New York have reportedly yielded almost 17,000 pounds of dry biomass per acre.

Submersed leaves of waterchestnut are pinnate (feather-like) and superficially resemble the finely dissected leaves of milfoils (*Myriophyllum* spp.). Submersed leaves are up to 4″ long and are attached to the flexible stem in a whorl. Surface or floating leaves are palmate (divided like the fingers on a hand) and form a rosette of leaves that can be as broad as 1 foot in diameter. Leaf blades are 1 to 2″ long and diamond shaped with a coarsely serrated (saw-toothed) margin. The upper sides of the leaves are bright green and the undersides are yellow-green with prominent veins. Rosettes form below the water surface and elongate to the surface by late spring – plants are buoyant due to inflated petioles or leafstalks (bladders) just below the rosette of leaves. Surface rosettes may initially be hidden within beds of other plants that produce floating leaves [e.g., watershield (*Brasenia* spp.), spatterdock (*Nuphar* spp.) and white waterlilies (*Nymphaea* spp.)] and by smaller floating plants such as duckweed (*Lemna* spp.), watermeal (*Wolffia* spp.) (Chapter 15.10) and filamentous algae (Chapter 13). However, the prolific growth of waterchestnut will eventually create dense monocultures with as many as 50 rosettes per square yard and will crowd out desirable native plants. Beds of waterchestnut can be so extensive that they may completely cover the shallow zones of lakes and rivers and may obscure the margin between land and water.

Waterchestnut produces a single-seeded four-pronged nutlet with barbed spines. This structure is only produced by *Trapa natans* var. *natans* and allows for easy identification of the variety. The barbed spines are sharp enough to penetrate a wet suit – a painful experience for anyone unfortunate enough to step on one of these nutlets – and are the basis for the imaginative common names given to this plant. In addition to wreaking havoc on divers and swimmers, these nutlets figure prominently in the spread and propagation of this invasive species.

Reproduction

Many invasive species spread and reproduce from fragments, tubers, turions or underwater runners or stolons, but waterchestnut is an annual that reproduces solely from seeds. Small white flowers with yellow stamens are produced on the rosette after June, then drop into the water during summer and mature as nutlets between July and September. Each rosette produces 10 to 15 nutlets, which are capable of persisting for 10 to 15 years if kept moist in the sediment. Nutlets are around 1″ wide, approximately 20% more dense than water and change from fleshy green to woody black by late summer. Mature nutlets drop from the plant and quickly sink into the sediment or wash to the shoreline, where the barbed spikes anchor the nutlet into the sediment. Parent plants disintegrate in the fall and seeds begin to germinate within a month after water temperatures warm to 50 °F or higher the following spring. A single nutlet can produce multiple rosettes because the rhizome can branch laterally to produce multiple upright stems.

Nutlets migrate between bodies of water by a variety of means. The most conspicuous vector for many years was humans, who intentionally introduced the waterchestnut as an ornamental. *Trapa natans* is listed as a federal "species of concern", but there are currently no explicit federal transport restrictions. Fortunately, a new appreciation of the environmental and economic problems that accompany establishment of this species and a network of state laws (including laws in NY, VT, NH, FL, MN and ME) that prohibit its transport have greatly reduced intentional introduction of waterchestnut. However, nutlets continue to move on currents between connected waterways, on the feathers, talons and webbed feet of numerous waterfowl and furred mammals, and especially on boat propellers, trailers and even foam bumpers on canoes.

Problems associated with waterchestnut

Infestations of waterchestnut cause problems similar to those of other invasive aquatic plants. Waterchestnut can form dense surface canopies that reduce sunlight penetration into the water column by 95% and crowd out other submersed and floating-leaved native plants and the fauna that rely on these plants for food and shelter. There is strong evidence that vallisneria or water celery (*Vallisneria americana*), a highly valued native plant, has been eliminated from many parts of the Hudson River after colonization by waterchestnut. This is due to the reduction in habitat available to vallisneria and to depletion of dissolved oxygen under large waterchestnut canopies, which also has a negative effect on small invertebrates. Large populations of waterchestnut create hostile environments for many desirable species such as banded killifish and spottail shiner and are often inhabited by fauna that are more tolerant of adverse conditions, including rough fish species such as the common carp. Dense beds of waterchestnut can also entrap predatory birds seeking food within and underneath the surface canopy. Although waterchestnut canopies could potentially create significant pockets of still water to support mosquitoes, this has not been well documented in North American populations of waterchestnut.

Waterchestnut often grows under eutrophic conditions, in part because eutrophic bodies of water often create the thick organic sediments preferred by this plant and in part because waterchestnut grows in shallow waters where poor water clarity found in eutrophic waterways does not limit plant growth. Thick masses of leaves and stems generated by waterchestnut degrade and settle into the bottom sediments, which increases the organic content (and depth) of the sediment and contributes to greater turbidity and a cycle of increasing eutrophication. Bacterial degradation of this plant material can reduce dissolved oxygen, particularly at the end of the daily respiration cycle and when plants rapidly degrade in response to active management, such as herbicide treatment. Plant tissues also accumulate some heavy metals; this may occur with other highly abundant aquatic plants as well and may ultimately be a net benefit since these metals are removed from sediments or the water column.

Dense surface canopies of waterchestnut reduce water flow and impede boating and other forms of non-contact recreation, a particularly vexing problem since this plant often dominates navigable rivers and slow-moving water around marinas. Unlike submersed invasive plants and most floating-leaved plants, waterchestnut creates canopies that are impenetrable by even canoes and kayaks – the rosettes swallow paddles and significantly retard the momentum of the paddler. The same shallow waters frequented by canoers and kayakers are sometimes used for swimming, although the soft, thick organic sediments usually needed to support waterchestnut plants do not provide the ideal habitat for waders and swimmers. Waders willing to slog through dense populations of waterchestnut must carefully navigate through the nutlets commonly found along the shoreline and in the upper layer of near-shore sediments since stepping on the sharp barbs can cause deep puncture wounds. Dense mats create an additional safety concern – entanglement in waterchestnut beds may have contributed to drowning deaths in the Hudson River in 2001.

The most significant impact of waterchestnut infestations on humans may well be a reduction in aesthetics. Dense waterchestnut beds can completely cover the surface of shallow bodies of water and small ponds and will often carpet the near-shore areas of popular navigable rivers. The description grudgingly applied to waterhyacinth (Chapter 15.7) – "chokes out a water surface" – applies to waterchestnut as well.

Management options

During the past 100 years, many techniques have been used to manage waterchestnut. Unlike most invasive aquatic plants, waterchestnut has been effectively controlled and perhaps even eradicated in some bodies of water, but only after persistent effort. As with other invasive plants, best management of waterchestnut results from a vigilant prevention program. Weed watcher programs are particularly effective in controlling waterchestnut since the species is easily identified.

Once present in a body of water, waterchestnut can be controlled by physical and chemical techniques and may ultimately be managed by biological agents. Initial infestations, particularly when only a single rosette is found, can be pulled by hand (Chapter 6). The best window for removal of waterchestnut is from mid-June to mid-August – earlier efforts may result in regrowth or incomplete removal of nutlets, whereas later attempts might miss some nutlets or cause loosely attached seeds to dislodge. Plants should be flipped upside down immediately after removal to prevent dropping of seeds. Kayaks or canoes can be used for hand removal of waterchestnut; kayaks are more easily maneuvered through dense beds of waterchestnuts, but canoes carry more chestnut cargo. Hand removal programs led by cooperative extension offices, community groups, Boy Scout troops and volunteers have effectively controlled waterchestnut in Oneida Lake in central NY and in countless other smaller bodies of water throughout the Northeast.

Mechanical harvesting (Chapter 7) can effectively control large infestations of waterchestnut since the species is not spread by fragmentation, although cutting just the leaves (rosettes) from plants will likely leave nutlets in the system. Mechanical harvesting of plants after seeds have formed but before they mature can effectively break the reproductive cycle of the plant; however, the longevity and quantity of seeds in the sediment's seed bank may make it necessary to repeat the operation for at least 5 to 10 years to eradicate the species. A variety of state and federal agencies have used large mechanical harvesters to greatly reduce waterchestnut populations in Lake Champlain in Vermont and New York and in the Mohawk and Potomac Rivers. However, populations rapidly rebounded and returned to pre-harvesting densities when harvesting was suspended due to loss of funding.

Herbicides have also been used to control large-scale infestations of waterchestnut (Chapter 11). The herbicide used most often for control of this aquatic weed is 2,4–D, which is usually applied in early summer when plants are just reaching the water surface. Recently, triclopyr has also been used to control waterchestnut. Research is underway to determine whether glyphosate provides control of waterchestnut when applied directly to the rosette of surface leaves.

Grass carp (Chapter 10) have been used as biocontrol agents to manage waterchestnut in some bodies of water. However, grass carp are relatively indiscriminate feeders that find waterchestnut to be unpalatable, so few plants are consumed. Insect-based biocontrol (Chapter 9) may be a more promising alternative; researchers are currently evaluating a native leaf beetle (*Galerucella birmanica*) which has shown promise. However, this native beetle is a generalist feeder that consumes plants other than waterchestnut. Because successful biocontrol agents must be species-specific and feed only on a particular host plant (Chapter 8), this native beetle may not be a viable biocontrol option for waterchestnut.

Summary

Waterchestnut is one of the most invasive aquatic plants in the northeastern United States and has spread from its introduced range into neighboring states over the last 125 years. This species creates significant ecological damage, restricts human use of waterways and can be very difficult to control without consistent and persistent effort. However, waterchestnut is unique among invasive aquatic plants because it is easily detectable through citizen watch programs and can be controlled or even eradicated if caught early in its colonization. The species is an annual and can be managed by preventing seed production. Once established, waterchestnut requires significant resources to manage and vigilant use of mechanical or chemical control methods for 10 to 15 years to exhaust the reservoir of dormant seeds harbored in sediments.

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Photo and illustration credits:

Page 139: Waterchestnut infestation; The Nature Conservancy (photographer unknown)

Page 140: Line drawing; Barre Hellquist. From Crow GE and CB Hellquist. 1983. Aquatic vascular plants of New England: part 6. *Trapaceae*, *Haloragaceae*, *Hippuridaceae*. Station Bulletin 524. New Hampshire Agricultural Experiment Station, University of New Hampshire, Durham, NH.

Page 142: Waterchestnut plant; Hilary Smith, The Nature Conservancy

Chapter 15.7: Waterhyacinth

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Eichhornia crassipes (Mart.) Solms; floating plant in the Pontederiaceae (pickerelweed) family
Derived from *Eichhorn* [Johann Albrecht Friedrich Eichhorn (1779-1856), Prussian minister of education and public welfare] and *crass* (Latin: thick)
"plant with thick leaf stalks"

Introduced from Brazil to New Orleans in 1884
Present throughout the southeastern US and California, Hawaii and the Caribbean area

Introduction and spread

Eichhornia crassipes is one of around seven species in the genus *Eichhornia*, all of which are native to South America. Waterhyacinth is native to the Amazon River and has been widely introduced throughout the tropical regions of the world, most recently occurring in Lake Victoria in East Africa.

The first known introduction of waterhyacinth to North America was at the Cotton States Exposition in New Orleans in 1884. The species was initially cultivated as an ornamental but quickly escaped cultivation and invaded other parts of the southeastern US. Waterhyacinth must have been a botanical curiosity due to its size, floating growth habit and the beauty of its very short-lived purple flower spikes. Mr. Fuller (the owner of Edgewater Grove, 7 miles upstream of Palatka on the St. Johns River) introduced this "beauty" to Florida around 1890. It was initially grown in Mr. Fuller's fountain pond and excess growth was cast into the St. Johns River, where within a short time it covered the half-mile wide river from bank to bank at several locations. Waterhyacinth spreads very rapidly; for example, the species covered 126,000 acres of Florida's surface water within 70 years of its arrival in that state. Waterhyacinth is present throughout the southeastern US, California, Hawaii and the Virgin Islands, but is considered eradicated in Arizona, Arkansas and Washington State. Populations of waterhyacinth have been reported in other states, including New York, Kentucky, Tennessee and Missouri and plants are intentionally introduced to farm fish ponds in southern Arizona and southern Delaware. This species is not cold-hardy and has not established permanent populations in more temperate areas outside the southern US. Waterhyacinth will survive moderate freezes but requires temperatures of greater than 50 °F to produce new growth. A number of states, including Florida, South Carolina and Puerto Rico, prohibit the sale of waterhyacinth, but the species is still available for purchase from aquarium supply stores, aquatic plant nurseries and internet sources in other states. Waterhyacinth spreads in natural systems by producing seedlings and daughter rosettes – small plantlets that are attached to the mother plant by a floating stolon or runner. Rosettes can easily become caught in boat trailers or live wells, which results in the introduction of the species to new bodies of water. Waterhyacinth is also spread by uninformed water garden and pond owners, who (along with Mr. Fuller in the 1890s) believe they are beautifying canals and lakes by tossing extra plants into natural systems.

Description of the species

Waterhyacinth is a floating flowering monocot that grows as an annual (in temperate regions) or as a perennial (in tropical and subtropical climates) in all types of bodies of water. Muddy or turbid water often limits growth of submersed plants, but because waterhyacinth is a floating plant, it is unaffected by these conditions. The leaves of waterhyacinth are thick, glossy, waterproof and rounded with a heart-shaped base. Each leaf can reach up to three feet in length and is borne singly on a spongy, inflated petiole (leaf stalk). Leaves are attached to one another at the base of the petiole to form a rosette that is free-floating, although plants will sometimes root in soft saturated sediments when stranded by drought or wave action. The dark purple to black roots of waterhyacinth are long and feathery and hang beneath the rosette of leaves. Waterhyacinth grows throughout the year in the tropics, but freezing temperatures kill the leaves of the plant in the northern portions of its range. Cold-damaged leaves then fold down and protect the meristem, which grows at or immediately below the surface of the water.

The most striking feature of waterhyacinth is the spike of large, showy flowers produced from the center of the rosette of leaves. Flowers are borne in groups of 8 to 15 on a single spike that can rise up to 20″ above the rosette. Each flower is up to 3″ tall and has six lavender-blue to purple petals, with the uppermost petal marked by a yellow "eye-spot." Flowers are short-lived, with each lasting only one or two days, but a spike may be showy for up to a week since only a few flowers open each day. Flowering is indeterminate – flowers at the base of the spike open first and flowers at the top of the spike open last. After flowers are fertilized, the spike bends and dips into the water, where many tiny seeds are produced in capsules. Mature seeds drop to the bottom of the body of water, where they remain dormant until sediments are exposed after water levels fall due to drought.

Waterhyacinth is sometimes confused with native frog's-bit (*Limnobium spongia*), because both are floating plants with rounded leaves borne in rosettes. However, the roots of waterhyacinth are black and feathery, whereas the roots of frog's-bit are thicker and white. In addition, the petioles of frog's-bit are usually slender, while the petioles of waterhyacinth are often spongy and bladder-like. Finally, flowers of frog's-bit are small, white and much less showy than those of waterhyacinth.

Reproduction

Waterhyacinth spreads by both seed and vegetative reproduction. As noted above, seeds are tiny and remain dormant until conditions are favorable for germination. Some reports suggest that seeds germinate best after they have dried and others say that seeds must be exposed to alternating warm and cold temperatures before they will germinate. Seed reproduction can be important in temperate climates since waterhyacinth is killed by freezing temperatures and recolonization in spring may be dependent on the seed bank established during the previous growing seasons. Once seeds have germinated and conditions are favorable for growth, waterhyacinth rapidly produces new daughter plants, or ramets, from horizontally growing stolons. Daughter plants can be produced in as little as 5 days under optimal growing conditions and populations can double in size in as little as 6 to 18 days, so the rapid growth and spread of waterhyacinth is due primarily to this type of vegetative reproduction.

Problems associated with waterhyacinth

Waterhyacinth grows almost entirely on the surface of the water as a floating plant and its growth potential is limited only by temperature and the availability of nutrients. Waterhyacinth prefers an environment similar to that favored by desirable fish populations – mesotrophic and eutrophic habitats with an adequate supply of calcium and a pH ranging from 6.5 to 9.5. There is no doubt that waterhyacinth is a serious aquatic weed. Under optimum conditions, an undisturbed population of waterhyacinth is composed of about 10 plants per square foot and has a fresh weight of 10 pounds. An acre (43,560 square feet) of waterhyacinth would therefore be home to about 435,600 plants with a fresh weight of around 200 tons. Since 95% of the plant weight is attributable to water, only 5% of the fresh weight – about 10 tons per acre – remains after plants are harvested and dried.

Waterhyacinth may not be as productive as most agricultural crops; however, trying to remove or stop 200 tons of live waterhyacinths from jamming against a bridge or clogging a waterway is no simple task! Large colonies of linked mother and daughter plants form dense rafts or mats that can quickly cover a body of water from shore to shore. Left undisturbed, floating mats of waterhyacinth provide a perfect substrate or "island" to support the growth of additional grasses, herbaceous plants and even small trees, which further bind the floating mat together. These mats interfere with human use of waters. For example, large populations of waterhyacinth can restrict recreational and commercial activities and can make boating, fishing and swimming impossible. In addition, water flow is greatly reduced where mats of waterhyacinth are present, which can impede irrigation and flood control efforts. Infestations of waterhyacinth can have serious ecological impacts as well. Dense waterhyacinth populations also reduce species richness or plant diversity by limiting light availability to native submersed plants and by crushing communities of emergent plants along the shoreline. The loss of these plants also eliminates habitats for animals that depend on native plants for shelter, nesting and food. In addition, large mats block the air-water interface and reduce dissolved oxygen, which makes the system uninhabitable to fish and other aquatic fauna.

Management options

The best method to control waterhyacinth is to prevent the species from entering a water body. The sale and interstate shipment of a closely related species [rooted waterhyacinth (*E. azurea*)] is prohibited by the Federal Noxious Weed List and its introduction into the US has been avoided thus far. Waterhyacinth (*E. crassipes*) is not on the Federal Noxious Weeds List because the species was already widely distributed in the US at the time the Federal Noxious Weed Acts were developed. In spite of these prohibitions, waterhyacinth still manages to slowly increase its range and to colonize new bodies of water.

Physical (Chapter 6) or mechanical (Chapter 7) control measures such as hand removal or mechanical harvesters should be designed to prevent the spread of waterhyacinth plantlets to other parts of the water body. Hand removal is labor-intensive and typically involves raking plants to the shoreline or into a boat. This very laborious task can seem deceptively easy; a pond that is a single acre in size may look small, but can host up to 200 tons of waterhyacinth that must be pulled out by hand! Plants are then offloaded along the shoreline until they desiccate and die. Hand removal may be an effective means to control waterhyacinth in small ponds, but is not practical in larger systems. Mechanical harvesting is usually used to remove plants from larger systems and involves heavy machinery that ranges from a backhoe on a barge to specialized equipment. A problem associated with mechanical harvesting of waterhyacinth is disposal of the harvested plants. Waterhyacinth vegetation has been used to make furniture, baskets and other items in some parts of the world and has been evaluated for its potential as mulch, cattle feed, biofuel production and other uses, but its utility is very limited. As a result, most harvested waterhyacinth is generally disposed of in farm fields or a landfill. Hand removal of waterhyacinth from ponds is best employed after herbicide application has been used to control the majority of the plants. Regular removal of missed plants and any plants growing from seeds after herbicide treatment will prevent waterhyacinth from reinfesting the pond.

Drawdowns can be used to "strand" and desiccate waterhyacinth on exposed shorelines, but the time required to effectively dry large mats of plants can be long. Also, drawdowns and drought have been known to trigger seed germination and plants reestablish quickly when water levels rise. Therefore, most waterhyacinth management programs in the US rely on the use of herbicides in conjunction with established insect biocontrol agents. Waterhyacinth weevils (*Neochetina* spp.) were introduced and established in the early 1970s (Chapter 9). The weevils are found throughout the range of waterhyacinth but in most areas the insects only slow plant growth and reproduction and do not provide adequate control of the weed. As a result, herbicides are used in maintenance control programs to keep plant populations low and to reduce growth potential of waterhyacinth. Herbicide selection is based on water use, selectivity to reduce damage to nontarget native plants and cost (Chapter 11). Several herbicides are commonly used as foliar sprays to selectively control waterhyacinth. Contact herbicides – including diquat, flumioxazin and endothall – are quickly absorbed by plant tissue and are fast-acting, whereas systemic herbicides – including 2,4–D, glyphosate, imazamox, penoxsulam and bispyribac – provide slower but effective control.

Summary

Waterhyacinth is one of the world's worst aquatic weeds and causes problems in all tropical and subtropical continents. Its current distribution in the US is primarily from East Central Texas to the Atlantic Coast and north to coastal North Carolina. It also occurs in the Sacramento River Delta in California. Although waterhyacinth is occasionally found north of the central US, the species typically does not persist where waterways are subject to ice formation and prolonged freezing temperatures. Florida and the Gulf states are particularly impacted by waterhyacinth due to the moderate climate and shallow, naturally nutrient-rich lakes, but the species can colonize virtually any region in North America where winter temperatures remain above freezing and mesotrophic or eutrophic waters are present. Aggressive maintenance control programs have kept populations of waterhyacinth in check in most areas, but these efforts must be employed on a continual basis to avoid population explosions of this noxious invasive species.

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Page 145: Waterhyacinth infestation; University of Florida Center for Aquatic and Invasive Plants (photographer unknown)
Page 146: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 147: Waterhyacinth; University of Florida Center for Aquatic and Invasive Plants (photographer unknown)

Chapter 15.8: Waterlettuce

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Pistia stratiotes L.; floating plant in the Araceae (Arum) family
Derived from the Greek *pistos* (water) and *stratiotes* (a common soldier)

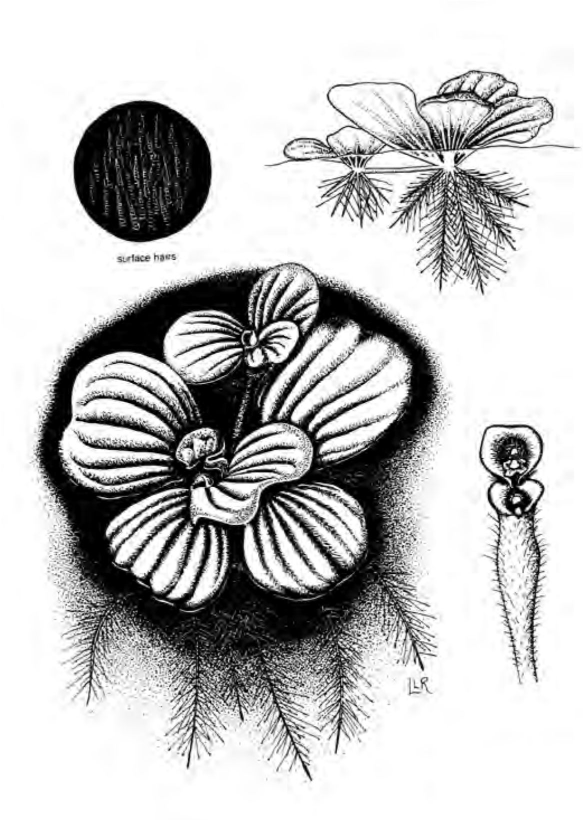
Introduction history uncertain, considered native to the southeastern US by some sources
Present throughout the southeastern US north to New Jersey and New York, west to Texas, Arizona and California; also present in Idaho, Ontario, Hawaii, Puerto Rico and the Caribbean

Introduction and spread

Pistia stratiotes is the only species in the genus *Pistia*. The origin of waterlettuce is unclear, but various sources suggest the plant is native to South America, Africa or the southeastern US. Waterlettuce is cosmopolitan in distribution and has been documented in aquatic systems around the world. The species is considered one of the world's worst weeds and is a noxious species in most regions where it has been introduced, such as Hawaii, Australia and the Canary Islands. In addition, waterlettuce is considered invasive in the US, Puerto Rico and Africa, despite reports that the species could be native to these areas.

Fossil records show that waterlettuce was present in Africa, the species' center of diversity, 85 million years ago and that the plant was present in Florida at least 50 million years ago. The first modern report of waterlettuce in North America was made by John and William Bartram, who described dense, nearly impenetrable populations of the species while surveying the St. Johns River in Florida on New Year's Eve in 1765. The USDA considers waterlettuce to be native to the continental US and does not categorize the species as a noxious weed, but a number of state lists include waterlettuce as a noxious, invasive or prohibited plant.

Although not as productive as waterhyacinth (Chapter 15.7), waterlettuce spreads very rapidly and can double its population size in as little as a few weeks, so it can quickly cover the surface of invaded waters. The species is not cold-hardy and rarely establishes permanent populations in temperate areas. Waterlettuce will survive moderate freezes but requires temperatures of greater than 50 °F to produce new growth. A number of states – including Alabama, California, Connecticut, Florida, South Carolina and Texas – prohibit the sale of waterlettuce, but the species is still available for purchase from aquarium supply stores, aquatic plant nurseries and internet sources in other states. The species continues to inhabit many bodies of water in Florida, along with aquatic systems throughout most of the southeastern and southwestern US, Hawaii, Puerto Rico and the Virgin Islands. Despite the well-documented problems associated with waterlettuce, the species is still widely cultivated as an ornamental in water gardens and has been evaluated for its utility as a phytoremediation agent to reduce nutrients and heavy metals in contaminated waters.



Waterlettuce spreads in natural systems by producing seedlings and daughter rosettes – small plantlets that are attached to the mother plant by a floating stolon or runner. Rosettes can easily become caught on boat trailers or in live wells, which results in the introduction of the species to new bodies of water. Waterlettuce is also spread accidentally as a result of escapes from cultivation and intentionally by uninformed water garden and pond owners, who believe they are beautifying canals and lakes by tossing extra plants into natural systems.

Description of the species

Waterlettuce is a floating flowering monocot that grows as an annual (in temperate regions) or as a perennial (in tropical and subtropical climates) in all types of bodies of water. Muddy or turbid water often limits growth of submersed plants, but since waterlettuce is a floating plant, it is unaffected by these conditions. The leaves of waterlettuce have wavy or scalloped margins and are thick, light green, covered with short hairs and water-repellant. Each leaf can reach up to one foot in length; leaves are attached to one another at the plant's base to form a free-floating rosette (although plants will sometimes root in soft saturated sediments when stranded by drought or wave action). The white to tan roots of waterlettuce are long and feathery and hang beneath the rosette of leaves. Waterlettuce grows throughout the year in the tropics, but freezing temperatures kill the leaves of the plant in the northern portions of its range.

The flowers of waterlettuce are borne in a spathe and spadix arrangement. The greenish spadix, a spike-like structure in the center of the inflorescence that houses separate female and male flowers, is sheathed by the white spathe, a hairy leaf-like bract. Although other members of the Araceae family – including caladiums, peace lilies and anthuriums – are ornamental species that are prized for their showy inflorescences, the spathe and spadix of waterlettuce is small and inconspicuous. It was long thought that waterlettuce did not produce seeds and that all reproduction by the species was vegetative via the formation of daughter plants; however, it is now known that waterlettuce produces copious, viable seeds and that this strategy allows the plant to maintain a presence in areas where droughts or winter freezes kill mature plants.

Reproduction

Waterlettuce spreads by both seed and vegetative reproduction. Each plant produces multiple fruits and each 2mm-long fruit can contain up to 20 tiny, golden-brown seeds. As a result, hundreds of seeds may be produced per square foot of coverage. Most seeds remain in the upper 2" of sediments and germination can be greater than 90%. Seed reproduction can be important in temperate climates since waterlettuce is killed by freezing temperatures and recolonization in spring may be dependent on the seed bank established during the previous growing seasons. Once seeds have germinated and conditions are favorable for growth, waterlettuce rapidly produces new daughter plants from horizontally growing stolons. In fact, the rapid growth and spread of waterlettuce during the growing season is due primarily to vegetative reproduction.

Problems associated with waterlettuce

Waterlettuce grows almost entirely on the surface of the water as a floating plant and its growth potential is limited only by temperature and the availability of nutrients. Waterlettuce prefers a habitat similar to that favored by desirable fish populations – mesotrophic and eutrophic waters with sufficient calcium and a pH ranging from 6.5 to 7.2. There is no doubt that waterlettuce is a serious aquatic weed, regardless of whether the species is native or introduced to the southeastern US. Under optimum conditions, a population of waterlettuce is composed of as many as 100 plants per square foot with a combined fresh weight of up to 5 pounds. An acre (43,560 square feet) of waterlettuce could therefore have millions of plants and a fresh weight of around 100 tons. Since 95% of the plant weight is attributable to water, only 5% of the fresh weight – about 5 tons per acre – remains after plants are harvested and dried.

Large colonies of linked mother and daughter waterlettuce plants form dense mats that can quickly cover a body of water from shore to shore and interfere with human use of waters. For example, large populations of waterlettuce can drastically impede boating, fishing and swimming and commercial activities. Also, water flow is greatly reduced where mats of waterlettuce occur, which hinders irrigation and flood control efforts. Several species of mosquito are known to breed in water held in the rosettes of waterlettuce; in fact, the larvae of some of these disease-causing insects attach to the underwater roots of waterlettuce and obtain oxygen through air tubes they insert into the plant's roots (Chapter 5). Infestations of waterlettuce can have serious ecological impacts as well. Dense waterlettuce populations reduce species richness or plant diversity by limiting the light that reaches native submersed plants and by crushing communities of emergent plants along the shoreline. The loss of these native plants also eliminates habitats for animals that depend on native plants for shelter, nesting and food. In addition, large mats block the air-water interface and reduce dissolved oxygen, which often makes the system uninhabitable to fish and other aquatic fauna.

Management options

The best method to control waterlettuce is to prevent the species from entering a water body. Waterlettuce is not on the Federal Noxious Weeds List. However, waterlettuce is on the State Noxious Weed Lists of Alabama, California, Connecticut, Florida, Puerto Rico, South Carolina and Texas, so its sale and transport is prohibited in these states. Even in states where waterlettuce is listed, it is easy to purchase plants at farmers' markets, local plant sales, on the internet and from other unregulated sources. Although waterlettuce has been deemed eradicated in some invaded areas such as small field sites in New Zealand, it is difficult or impossible to completely eliminate waterlettuce once a body of water has been invaded. Between existing populations that are left uncontrolled, accidental transfer from infested areas and escapes from cultivation, waterlettuce still manages to slowly increase its range and to colonize new bodies of water.

Physical or mechanical control measures such as hand removal or mechanical harvesters should be designed to prevent the spread of waterlettuce plantlets to other parts of the water body (Chapters 6 and 7). Hand removal is labor-intensive and typically involves raking plants to the shoreline or into a boat. This may seem like a simple job, especially in a small pond; however, a single acre can support as much as 100 tons of waterlettuce that must be pulled out by hand! Plants are then offloaded along the shoreline until they desiccate and die. Hand removal may be an effective means to control waterlettuce in small ponds, but is not practical in larger systems. Mechanical harvesting is usually used to remove plants from larger systems and involves heavy machinery that ranges from a backhoe on a barge to specialized equipment. A problem associated with mechanical harvesting of waterlettuce is disposal of the harvested plants. There are no large-scale uses of harvested waterlettuce, so most plant material is usually disposed of in farm fields or a landfill.

Drawdowns can be used to "strand" and desiccate waterlettuce on exposed shorelines, but the time needed to effectively dry large mats of plants can be long. Also, drawdowns and drought have been known to trigger seed germination of other invasive species such as waterhyacinth. Although there are as many as 50 species of insects that feed on waterlettuce, only two have met the criteria for biocontrol agents (Chapter 9). The waterlettuce leaf moth (*Spodoptera pectinicornis*) was imported from Thailand and released in Florida in 1990, but failed to establish. The waterlettuce leaf weevil (*Neohydronomus affinis*) was imported from South America to the US in mid-1980s and is now established throughout Florida, but its effect on waterlettuce growth is negligible. Therefore, most waterlettuce management programs in the US rely on the use of herbicides to keep plant populations low and to reduce growth potential of waterlettuce. Herbicide selection is based on water use, selectivity to reduce damage to non-target native plants and cost. Several herbicides can be used as foliar sprays to selectively control waterlettuce (Chapter 11). Contact herbicides such as diquat, carfentrazone and flumioxazin are quickly absorbed by plant tissue and cause obvious damage within a few days, whereas systemic herbicides such as imazapyr, penoxsulam and bispyribac provide slower but very effective control. Submersed application of the contact herbicide flumioxazin is currently being evaluated for selective control of waterlettuce, as are topramezone and the ALS herbicides.

Summary

Waterlettuce is one of the world's worst aquatic weeds and causes problems in virtually all waters it has invaded. It is currently distributed throughout the southeastern US north to New Jersey and New York, west to Texas, Arizona and California. While waterlettuce is found throughout New

England and other temperate regions, it typically does not persist where waterways are subject to ice formation and prolonged freezing temperatures. Florida and the Gulf states are particularly impacted by waterlettuce due to the moderate climate and shallow, naturally nutrient-rich lakes, but the species can colonize virtually any region in North America where winter temperatures remain above freezing and mesotrophic or eutrophic waters are present. Aggressive maintenance control programs have kept populations of waterlettuce in check in most areas, but these efforts have to be employed on a continual basis to avoid population explosions of this noxious invasive species.

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Photo and illustration credits:

Page 151: Infestation of waterlettuce; Lyn Gettys, University of Florida

Page 152: Line drawing; University of Florida Center for Aquatic and invasive Plants

Page 153: Spathe and spadix inflorescence of waterlettuce; Lyn Gettys, University of Florida

Page 154: Young waterlettuce with daughter plant; Lyn Gettys, University of Florida

Chapter 15.9: Giant and Common Salvinia

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Salvinia molesta D.S. Mitchell; *Salvinia minima* Baker; free-floating ferns in the Salviniaceae family. Derived from *Salvinia* (after Antonio M. Salvini) and *molesta* (Latin: nuisance, annoying, troublesome) and *minima* (Latin: small, minor)

Introduced from Brazil (*Salvinia molesta*), Central and South America (*Salvinia minima*)
Found throughout the southern US

Introduction and spread

Water ferns in the genus *Salvinia* are members of the Salviniaceae family. There are 12 species of *Salvinia* reported worldwide, seven of which originate from the New World tropics. None of the *Salvinia* species are native to North America, but two species – *Salvinia minima* and *Salvinia molesta* – have been introduced and are currently established in the US. Both species were likely introduced into the US through the nursery trade as ornamental plants for water gardens or through the aquarium plant industry.

Salvinia molesta, commonly known as giant salvinia, is native to southeastern Brazil and was first found outside its native range in Sri Lanka in 1939. Giant salvinia quickly became a widespread weed problem in Sri Lanka, infesting rice paddies, reducing flows in irrigation channels and blocking navigation in transportation canals. Today, giant salvinia is considered one of the world's worst weeds and has become established in over 20 countries including Africa, India, Indonesia, Malaysia, Singapore, Papua New Guinea, Australia, New Zealand, Fiji, Cuba, Trinidad, Borneo, Columbia, Guyana, the Philippines and Puerto Rico.

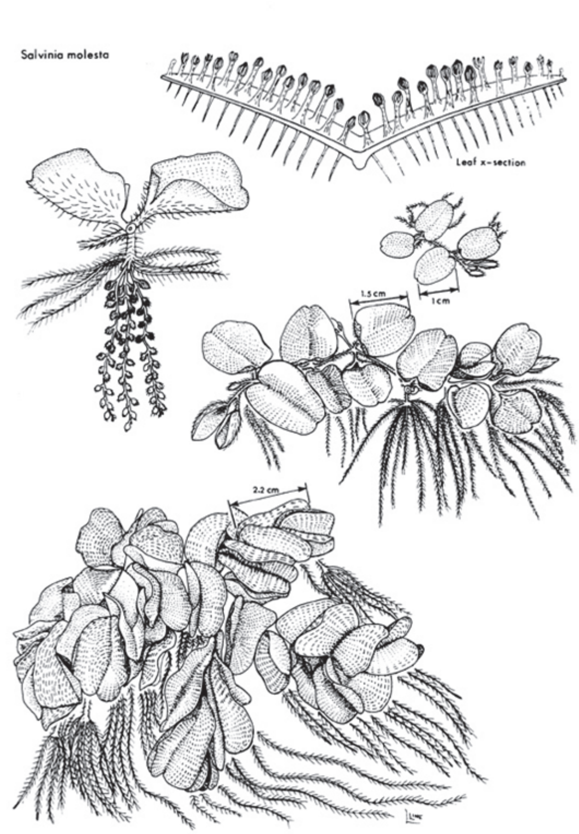
The first report of giant salvinia outside of cultivation in the US occurred in 1995 when it was discovered in a small, private pond in South Carolina. Once identified, it was quickly eradicated from this site with the use of herbicides. Although this initial infestation was successfully eradicated, giant salvinia has since been reintroduced and has spread throughout the southern US. Significant infestations have been reported in more than 90 locations in 41 freshwater drainage areas of 12 states including Alabama, Arizona, California, Georgia, Hawaii, Florida, Louisiana, Mississippi, North and South Carolina, Texas and Virginia. Giant salvinia is currently listed as a Federal Noxious Weed by the US Department of Agriculture (www.aphis.usda.gov/ppq/weeds/), which prohibits its importation into the US as well as its transport across state lines. However, giant salvinia must be listed as a noxious species by individual states to prohibit sale and cultivation of the species within that state. Since it is not currently designated as a noxious weed by all states, the expansion of giant salvinia will likely continue across the US. Quarantine and sale of this plant by the nursery industry has been difficult to enforce nationwide. In fact, a recent survey of mail-order catalogs and on-line commercial vendors for water garden enthusiasts revealed that giant salvinia was among the many noxious aquatic plants readily available for purchase over the internet.

Salvinia minima, hereafter referred to as common salvinia, is native to Central and South America. Outside its native range it has established in Bermuda, Puerto Rico, Spain and North America. Common salvinia was first reported in the US in 1928 along the St. John's River in Florida. The source of this first introduction to a natural area was likely the result of an unintentional release from a grower whose cultivation ponds had flooded. Since then, populations have been recorded in more than 80 freshwater drainage areas across southern and southeastern states including Texas, Arkansas, Louisiana, Mississippi, Alabama, Florida, North and South Carolina and Georgia. Similar to giant salvinia, common salvinia is widely available through the water garden trade. Although it continues to infest new regions, common salvinia is not listed as a Federal Noxious Weed; however, it is currently listed as a prohibited plant in the state of Texas.

Description of the species

Common and giant salvinia are free-floating aquatic ferns with a horizontal stem or rhizome that floats at or just below the water surface. A pair of floating leaves or fronds (leaves of ferns are referred to as "fronds") are produced at each node along the rhizome. Fronds are bright green in color, oval in shape, possess a central midrib and are covered with numerous stiff, white hairs. It is thought that the function of these leaf hairs is to repel water and thus aid in plant buoyancy. An easy way to distinguish giant salvinia from common salvinia is by the shape of the hairs on the upper surface of floating fronds. The hairs on the fronds of giant salvinia form cage-like structures at the tip that resemble an eggbeater or kitchen whisk, whereas the hairs on common salvinia fronds are open at the tip and have a fringed appearance (see page 160).

Common and giant salvinia lack true "roots" but possess delicate, finely-dissected submersed fronds. Submersed fronds are brown and resemble roots and serve a similar function by absorbing nutrients from the water. Sporocarps (structures that hold the fern's spores) are borne in chains or clusters on submersed stalks but do not bear fertile spores. Sporocarps are not found at all plant nodes but often develop and are more abundant later in the growing season or when nutrient conditions are poor.



Both giant and common salvinia favor stagnant or slow-moving water habitats of lakes, ponds, rivers, streams, oxbows, ditches, canals, swamps, marshes and rice fields. Under favorable growing conditions, both species can form dense, expansive plant mats that can completely cover the water surface. Optimal growing conditions include full sunlight and warm (75 to 85 °F), nutrient-rich waters with a pH of 6 to 7.5. Upper and lower temperature thresholds for growth are about 95 and 50 °F, respectively. Both giant and common salvinia have a low tolerance to salinity and cannot survive in brackish or marine environments.

Reproduction

Giant and common salvinia are ferns, so they do not produce flowers or seed. As mentioned above, both species produce sporocarps that may contain spores but the spores are not viable. As a result, giant and common salvinia reproduce solely by vegetative means through fragmentation or the production of new plants from lateral and terminal buds. Stems may have as many as 5 buds per node and each bud is capable of developing new fronds. In addition, horizontal stems or rhizomes break apart very easily and produce fragments that disperse and develop into mature individual plants.

An individual giant salvinia can double in size in as little as 5 to 7 days when conditions are favorable. Some reports have calculated that a single giant salvinia plant can multiply to cover 40 square miles in 3 months under optimal growing conditions. With such an explosive growth rate, giant salvinia can quickly cover lakes and rivers, forming vegetative mats up to 3 feet thick. Common salvinia also has a rapid growth rate and can form dense mats, but is often less aggressive than giant salvinia.

The major means of dispersal within and among lakes for giant and common salvinia is vegetative spread by fragmentation. Plant populations expand laterally within a lake through rhizome and lateral bud growth, whereas long distance dispersal is mostly the result of fragmentation. Plants

easily adhere to boats, trailers, motors and other amphibious vehicles and can be transported to new locations. Animals (livestock, turtles, wading birds and waterfowl) may also contribute to the spread and dispersal of salvinia.

Problems associated with giant and common salvinia

Both giant and common salvinia can alter aquatic ecosystems in many ways. Dense growths can form a physical barrier on the water surface and hinder recreational activities such as boating, swimming, fishing and water skiing. Vegetative mats of salvinia can also impede navigation, impair flood control, limit irrigation, clog water intakes, decrease waterfront property values and cause problems in rice, catfish and crawfish production systems. Occasionally, other plant species (including grasses and small trees) will colonize mats of giant salvinia and create massive floating islands that can trap sediments and cause waterbodies to fill in over time.

Ecologically, extensive salvinia mats can restrict light penetration and impede gas exchange between the water and atmosphere. Limiting light availability reduces photosynthesis of submersed aquatic plant communities and reduces water temperature. Low dissolved oxygen levels in the water are detrimental to fishes and other aquatic organisms and promote the accumulation of organic matter as microbial degradation is reduced. Changes in water quality can significantly impact the health of aquatic habitats and often result in declines in number and diversity of plant, invertebrate and animal communities. The loss of open water habitat also reduces the use of these areas by migrating waterfowl and wading birds (Chapters 3 and 4).

Public health issues are also of concern. Both species of salvinia provide breeding habitats for mosquitoes and associated mosquito-borne illnesses (e.g., West Nile virus, malaria, encephalitis—Chapter 5). In Sri Lanka, it was reported that giant salvinia served as an important host plant and breeding habitat for mosquitoes which transmit filariasis (elephantiasis). Increases in the occurrence of schistosomiasis have also been linked with large infestations of giant salvinia in developing countries.

Management options

Giant and common salvinia can be managed using herbicides, biocontrol agents, manual or mechanical harvesting, water level manipulation or a combination of these methods. Selecting the best management strategy depends on site-specific management goals and objectives, site characteristics, size and density of the infestation, proximity to sensitive plant or animal species, water body uses and budget constraints. The key to successfully managing giant and common salvinia is to recognize the problem early when infestations are small and can be easily contained. Once giant or common salvinia become well established and cover large areas, management becomes more difficult, time consuming and costly and may require multiple applications of a treatment method over a number of years to achieve maintenance control.

Herbicides (Chapter 11) can provide effective short and/or long-term control of giant and common salvinia depending on the choice of product and method of application. Of the herbicides currently registered by the US Environmental Protection Agency for use in aquatic sites, eight provide excellent control (> 90%) of giant or common salvinia. The most widely used herbicides against these weed species include diquat, glyphosate, flumioxazin and carfentrazone-ethyl. Diquat, flumioxazin and carfentrazone-ethyl are non-selective contact herbicides that are typically applied as foliar sprays. Injury symptoms (severe leaf browning) are visible one day following application and plant death occurs within 3 to 4 days of treatment. Contact herbicides are fast-acting but have little or no movement inside plant tissues, so only plant tissues that come into contact with the herbicide are affected. Glyphosate is a non-selective, systemic herbicide that is applied to foliage, absorbed through the leaves and moves throughout the plant. Injury symptoms (leaf yellowing and browning) appear seven days after glyphosate application and plant death occurs by 28 days after treatment.

Other systemic herbicides that are effective, but slower-acting and used to a lesser extent against these two salvinia species, include imazamox, fluridone, penoxsulam and bispyribac. Imazamox is effective on common salvinia but shows little or no activity on giant salvinia. Both species are susceptible to penoxsulam, bispyribac and fluridone. These herbicides require long contact times (60 to 90 days) to achieve control of salvinia, whereas imazamox has a shorter contact time requirement (7 days). Contact time refers to the length of time the target plant must be in contact with or exposed to a lethal dose of herbicide to achieve control. If contact time is not maintained because of water exchange or other factors that can cause dilution, plant control will be reduced. Imazamox and penoxsulam can be applied as a foliar spray or as a submersed application to the water column, whereas fluridone is effective only as an in-water treatment. Although in-water herbicide applications can be effective for treating these floating weed species, this method may not be feasible for sites where high water exchange or flow affect herbicide contact time and may be prohibitively expensive in larger systems.

Giant and common salvinia can be difficult to manage using herbicides because they are small floating plants that produce dense stands with plants layered on top of one another. This layering of plants presents a challenge when applying herbicides because plants in lower layers of the mats are protected from herbicides by plants in the upper layers of the mats. If plants are dense and a thick vegetative mat has formed, multiple applications will be required to achieve successful long-term control. In addition, giant and common salvinia can survive short dewatering or drawdown events and can persist on moist soils; therefore, spraying shoreline areas in addition to plants on the water surface is important to prevent reinfestation via surviving plant material. Long-term management with herbicides requires follow-up monitoring to spot-spray any plant material that survived the initial application. As a good management practice, herbicides should be routinely rotated and/or combined with other control strategies to minimize the potential development of herbicide resistance.

Several insects have been investigated as biological control agents (Chapters 8 and 9) against salvinia species, but the salvinia weevil (*Cyrtobagous salviniae*) is recognized throughout the world as the insect of choice for management of giant and common salvinia. This insect feeds and reproduces only on plants in the Salviniaceae family. The salvinia weevil is a small (less than 1/16" long) black weevil native to South America. Adults feed on floating fronds and rhizomes but prefer

newly formed buds. The larvae of the salvinia weevil are white, 1/8" long and feed within the floating and submersed fronds, rhizomes and buds. Feeding by the larvae is often more destructive than that of adults. The combined feeding action of adults and larvae can be devastating and can impact field populations of giant and common salvinia in several months as opposed to the longer periods of time required by other insect biocontrol agents. Attacked plants turn brown in small patches that merge together until the whole colony loses structural integrity, becomes waterlogged and sinks. Although never intentionally released, the salvinia weevil was first detected in Florida in 1960, where it is now widespread and feeds primarily on common salvinia. Initial attempts to release weevils collected from Florida to manage giant salvinia in Texas and Louisiana were ineffective. This prompted researchers to seek permission from the Technical Advisory Group and the USDA-APHIS-PPQ (US Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine – see Chapter 8), to release a strain of the salvinia weevil from Australia which was highly effective in overseas applications. Permission was granted in 2001 and the Australian weevils were released in east Texas and western Louisiana only. The weevils have since become established and are beginning to impact giant salvinia in these localized release sites.

Herbivorous fish such as triploid grass carp (Chapter 10) and tilapia (*Oreochromis* sp.) have been evaluated as possible biocontrol agents against salvinia with limited success. Laboratory feeding studies showed that while tilapia will consume giant salvinia, it is not their preferred food if other food sources are available. Other studies have shown that salvinia provides little nutritional benefit to herbivorous fishes.

The effectiveness of mechanical methods (Chapter 7) or manual removal is limited but may be useful in the early stages of an infestation or when a localized population is found on a small water body. If mechanical harvesting methods are employed, plant material must be properly disposed of in upland areas where the potential for contamination of other water bodies is minimized. Mechanical removal is not economically feasible once giant or common salvinia is well established and covers large areas. However, combining mechanical removal with herbicide applications can be an effective integrated weed management strategy. For example, in 2003, the Hawaii Department of Agriculture was successful in controlling 300 acres of giant salvinia on Lake Wilson on Oahu using multiple applications of the herbicide glyphosate combined with mechanical removal techniques. Excavated plant material was safely disposed of in nearby pineapple fields.

<u>Other management options</u> (Chapter 6). Floating booms have been used to contain and limit the spread of giant and common salvinia in some systems but are generally only utilized to confine plants to one location while other management strategies such as herbicides or weevils are deployed. Drawdowns can be a low-cost, effective management approach in some situations where water levels can be manipulated. However, dewatering must occur over a long period of time to allow plants to become stranded on dry land where they will desiccate and/or be exposed to freezing temperatures. Plant material can remain viable for several months if stranded shoreline mats are dense and underlying moisture is present. Decaying plant material along shorelines can be unsightly and plant fragments can easily be blown back into the system.

Summary

Giant and common salvinia are fast-growing, mat-forming aquatic ferns that can quickly cover the water surface of lakes, rivers and other wetland habitats. They are aggressive competitors that reproduce only by vegetative means. The plants can tolerate a wide range of growing conditions but prefer warm, nutrient-rich waters and full sunlight. Giant and common salvinia prefer freshwater environments and will not colonize saline or brackish waters. Once established, herbicides can be used to effectively manage these plants; however, multiple applications, follow-up monitoring and spot treatments may be required to maintain long-term control. Introducing insect biocontrol agents such as the salvinia weevil can be effective for maintenance control in some systems. The salvinia weevil has been especially successful in Florida for keeping common salvinia populations in check. Preventing the spread of this plant through citizen watch programs, boat launch surveillance and enforcement and compliance with laws to prevent the cultivation, sale and transport of these species will be important for containing and minimizing further spread of giant and common salvinia in the US.

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•Websites with information on giant and common salvinia: http://salvinia.er.usgs.gov/html/identification1.html http://salvinia.er.usgs.gov/index.html

Photo and illustration credits:

Page 157: Giant salvinia at Lake Wilson, Oahu; Linda Nelson, USACE ERDC

Page 159: Line drawing; University of Florida Center for Aquatic and Invasive Plants

Page 160 upper: Common salvinia; Ted Center, bugwood.org

Page 160 lower: Giant salvinia; Mic Julien, bugwood.org

Page 162: *Cyrtobagous salviniae* on giant salvinia frond; Scott Bauer, bugwood.org

Chapter 15.10: Duckweed and Watermeal – The World's Smallest Flowering Plants

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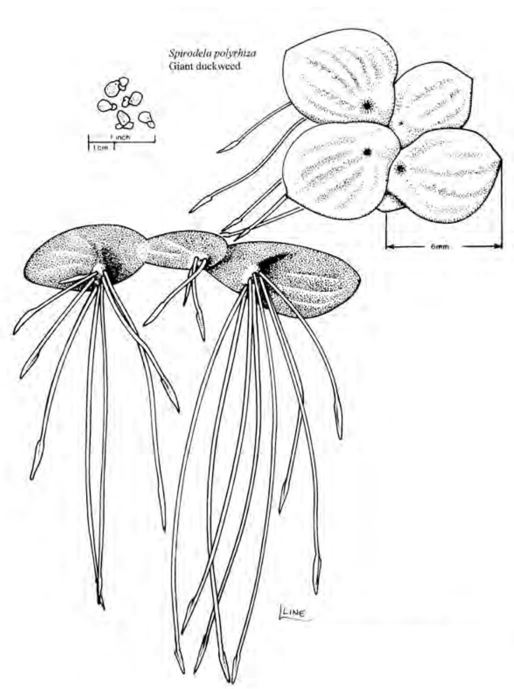
Duckweed species can grow so densely on water surfaces that they appear as finely groomed turf. They are considered the world's smallest flowering plants. To put their size and numbers in perspective, watermeal is approximately the size of a sugar crystal or a grain of salt, which translates to 5 to 10 billion plants per acre.

Introduction and spread

Duckweeds represent five genera of small floating aquatic plants in the *Araceae* subfamily *Lemnoideae* (although until recently duckweeds were considered members of the *Lemnaceae* or duckweed family). The duckweeds (*Landoltia*, *Lemna* and *Spirodela*), watermeal (*Wolffia*) and bogmat (*Wolffiella*) genera include more than 35 species worldwide; in this chapter, the term "duckweed" will refer to all members of these five genera. Multiple species are native to North America, such as *Spirodela polyrrhiza* (giant duckweed), *Lemna minor* (common duckweed), *Lemna minuta* (least duckweed) and *Lemna gibba* (swollen duckweed), but some species found in the US – including the Australian or Southeast Asian native dotted duckweed (*Landoltia punctata*) – are introduced. Duckweed is widespread in distribution and is found on every continent except Antarctica. Some species, like *Lemna minor*, are native to multiple continents. Growth rates are extremely high and populations can double in size in 1 to 3 days under optimal conditions. The diminutive size of duckweed allows plants to easily "hitchhike" on water currents, waterfowl and watercraft, which contributes to its spread.



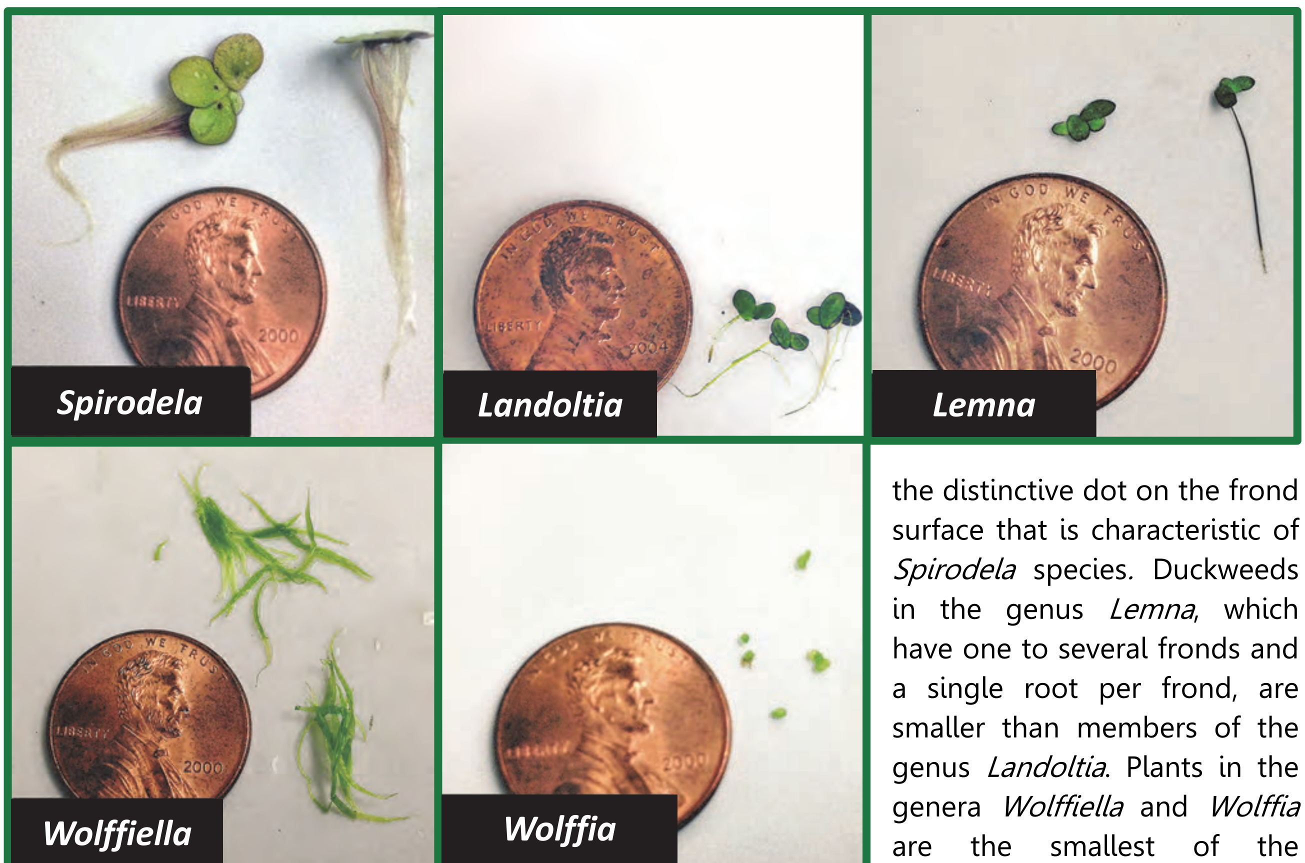
Although duckweeds are often a nuisance in backyard ponds, the plants are valued and used extensively for applied and basic plant science research. Duckweeds have many potential uses, including biofuel production and as a food source (duckweed reportedly tastes like spinach and is high in protein and vitamins). Duckweeds have also been used as bioremediation agents to clean up or remove waterborne nutrients and contaminants. These species can improve water quality in natural systems such as lakes and can reduce nitrogen, phosphorus and metal contamination in commercial waters such as swine-based effluent ponds before they are discharged to other waters, although this could accidentally introduce duckweeds to downstream systems.

Description of species

Duckweeds are monocotyledons and can be distinguished from other floating plants by their small size, which ranges from around a 1/25 of an inch to less than an inch. Duckweeds have the distinction of being the world's smallest flowering plants and some species, especially bogmat and watermeal, are commonly confused with algae. Another floating aquatic plant that could be confused with duckweed is the native mosquito fern (*Azolla caroliniana*). Mosquito ferns are diminutive like duckweeds but are branched instead of round and plants are often red, particularly when grown in full sun.

Duckweed species can be separated based on: 1) frond size, number and shape, and 2) root structure or lack thereof. Fronds are leaf-like structures and may be modified stem or leaf systems that absorb nutrients from the water column. The function of the modified root structure is not well understood (although the roots may help the plant stay in an upright position), and roots are lacking in the genera *Wolffiella* and *Wolffia*.

The largest duckweeds are up to one inch in diameter and belong to the genus *Spirodela*. Plants in this genus are also the most structurally complex of the duckweeds and have flowers and many roots per frond. Duckweeds in the genus *Landoltia* are similar to *Spirodela* duckweeds, but are smaller (around one third the size), have fewer roots (from several to one per frond) and usually lack the distinctive dot on the frond surface that is characteristic of *Spirodela* species. Duckweeds in the genus *Lemna*, which have one to several fronds and a single root per frond, are smaller than members of the genus *Landoltia*. Plants in the genera *Wolffiella* and *Wolffia* are the smallest of the duckweeds and have the least complex structure (no roots, simplified flowers). These genera can be identified by their fronds, which are long and spindly in *Wolffiella* and oval in *Wolffia*. Although it is fairly easy to distinguish among the duckweed genera, it is much more challenging to identify species within each genus, particularly in the *Lemna* duckweeds.



Duckweeds are typically found in still, nutrient-rich waters, and populations or colonies of tens of thousands of individual plants can thrive in small pools of water or ditches. Some duckweed species can survive cold (but not freezing) temperatures and increases in salinity can stimulate growth, although excess salinity can inhibit growth or kill plants. Duckweeds can provide habitat for many aquatic organisms such as insects and frogs and can be an important food source for wildlife, including fish and birds (hence the name "duckweed.")

Reproduction

Duckweeds are very productive and might very well be among the fastest growing plants. Despite being the smallest angiosperms, flowers are rarely seen due to size and blooming frequency. The small fruit produced is called a utricle. Duckweed primarily reproduces through asexual vegetative budding where each frond produces a new plant. This mode of growth can allow duckweed to quickly cover ponds and lakes with an extremely short doubling time. Multiple species can produce seeds and turions (or buds) for overwintering; one seed is produced per frond. Turions are modified structures that sink to the bottom of lakes where they overwinter, but not all duckweed species produce them. Seed production is a particularly important adaptation that allows survival of droughts. Seeds are reported to have extremely low survival (if any) after exposure to freezing conditions, which limits overwintering capabilities. However, duckweed seeds and turions are adapted to sink to the bottom of water bodies to escape freezing for insuring a viable propagule bank for growth in warmer conditions.

Problems associated with duckweed

Similar to filamentous algae, duckweed can form dense surface mats that are several layers thick and may include mixtures of different species. However, duckweed's ability to decrease light penetration and intensity and to consume nutrients can actually inhibit algal growth. Dissolved oxygen concentrations below duckweed mats are often low, which can influence the type and abundance of invertebrate and fish populations. Duckweed mats can also reduce aesthetics and recreational uses of water resources because their excessive growth covers the surface of the water. Duckweed usually causes problems in smaller bodies of water such as backyard ponds, canals, wetlands and other static sites. However, it has also created significant issues on some very large lakes, including Lake Maracaibo in Venezuela (South America's largest lake).

Management options

Duckweeds can present an extreme challenge to resource managers. Control methods provide only temporary relief; unless every plant is successfully managed, colonies will rapidly re-form because duckweeds reproduce so quickly. In addition, duckweed can survive on mud flats and wet shorelines, which allows them to escape management efforts. These missed plants can quickly re-infest a site once they are flushed back in to the water by wave action or rising water levels. In addition, upstream sources that host colonies of duckweed can also be a source of new introductions.

Floating booms and suction devices can be used to remove duckweed, and rakes can be used when wind and currents cause colonies to accumulate near banks or in isolated small areas (Chapters 6 and 7). However, mechanical harvesting is typically limited to smaller (< 1/2 acre) water bodies. Dyes do not provide control of duckweed and may actually promote growth of colonies by reducing algal competition. Aeration can relieve the low dissolved oxygen levels associated with large duckweed populations, thus improving fish habitat, but do not affect plant growth. Grass carp (Chapter 10) have been used to manage small infestations of duckweed, although high stocking rates (50 to 75 per acre) of small fish (4 to 6 inches) are needed to have an impact. It is important to remember that small grass carp are very susceptible to predation, so most stocking recommendations specify grass carp that are at least 10 to 12 inch long to reduce predation. However, grass carp that are this large have lost the ability to strain small plants from the water and have little utility for duckweed control.

Chemical control (Chapter 11) is the predominant method used to manage duckweed, but different species of duckweeds have differing susceptibilities to herbicides. For example, *Lemna* duckweeds are generally considered easier to control and more susceptible to herbicides than *Wolffia* (watermeal), which are the most difficult species of duckweeds to control. Since these plants often co-exist, it is possible to successfully control one species (*Lemna* duckweed) without causing significant damage to the other (watermeal). Therefore, proper identification of the genera targeted for management is very important. General guidelines for managing *Lemnoideae* species with herbicides are outlined below; however, it is important to remember that effectiveness of control methods are species-dependent and can vary.

There are multiple herbicides that may be used to control duckweed; these are generally separated into systemic and contact herbicides. Systemic herbicides can be divided into in-water systemic herbicides (absorbed by the plant primarily from the water column) and foliar-applied systemic herbicides (applied directly to the surface of the plant). In-water systemic herbicides are used to manage duckweed when populations cover large areas (or the entire surface) of a water body. These products are relatively easy to apply and, when effective, usually result in long-term control. In-water systemic herbicides can be applied to the surface of the water or can be injected directly into the water column and need to maintain contact with the plant for an extended period of time. Contact with every individual plant during the application is not required because in-water systemic herbicides diffuse through the water column. These herbicides are slow-acting, so large infestations can be treated without negatively affecting dissolved oxygen levels because plant death occurs over an extended period. Fluridone has historically been the most commonly used in-water systemic herbicide for duckweed control, but penoxsulam and bispyribac-sodium are also labeled to control duckweed. The foliar-applied systemic herbicides glyphosate and imazapyr are unlikely to provide long-term control of duckweed because these products become ineffective once they enter the water column.

Depending on conditions and the scale of application, contact herbicides such as diquat and flumioxazin may provide effective control of duckweed. (Note: *Wolffia* duckweeds are generally tolerant of diquat, so foliar applications of diquat alone are not recommended for control of *Wolffia* duckweeds. Foliar applications are also not recommended for *Wolffiella*, although this species is rarely targeted for control.) Other contact herbicides such as chelated coppers are labeled for duckweed control but are not commonly used unless local conditions or water-use restrictions limit other options. Contact herbicides are fast-acting with short half-lives in water, so they must be applied as a foliar application to the entire surface area of the duckweed population or as an in-water application to the entire water body. Surfactants (Chapter 12) should not be used when applying contact herbicides as a foliar treatment to duckweed because these products can cause plants to "sink", which washes the herbicide off the leaf surface and reduces efficacy. Foliar treatments that are applied by boat inevitably result in some wash-off as well. Care should be taken to avoid sinking or wash-off during the application process because good coverage is critical when using contact herbicides. Also, if duckweed colonies are extremely dense, mats might be several layers thick and a foliar application might kill only the plants on the surface of the mat. In this situation, plants in lower layers of the mat are unaffected and can quickly re-colonize the surface of the water. As a result, contact herbicide applications must often be repeated to control remaining plants that escaped direct exposure to the herbicide during the initial application.

Because contact herbicides act quickly, these products are typically applied to only part of the water body at one time; this helps to avoid the major reduction in dissolved oxygen that can occur when large populations of plants are killed. Some contact herbicides prohibit treating more than one-third to one-half of a water body if dense vegetation is present, but allow application of the product to untreated areas 10 to 14 days after the initial application. Contact herbicides should be used as early in the growing season as possible – before peak plant growth and while water temperatures are cooler – to help reduce oxygen depletion.

The first documented case of herbicide resistance in floating plants occurred in *Landoltia punctata*; however, this species' resistance to diquat was reduced when copper was applied in combination with diquat. Using a combination of systemic and contact herbicides (for example, fluridone plus flumioxazin) could improve efficacy and provide longer-term control at lower rates than either product would when applied individually.

Summary

Members of the five duckweed genera are widespread and occur on almost every continent. Despite their diminutive size, these plants can form dense multi-species colonies on the surface of the water, which decreases water quality and impedes recreational and other water resource uses. Mechanical and biological methods are sometimes used for management, but their use is often limited. However, there are several options for chemical control that can be used to manage nuisance colonies of duckweed.

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Page 165: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 166: Duckweed montage; Ben Willis, SePRO Corporation
Page 167: Duckweed infestation; Tyler Koschnick, SePRO Corporation

Chapter 15.11: Phragmites – Common Reed

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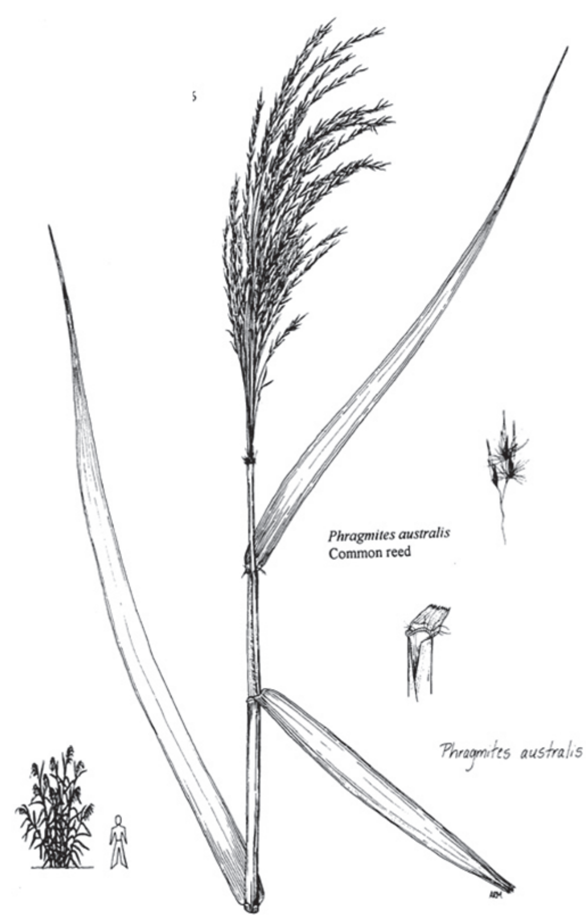
Phragmites australis (Cav.) Trin. Ex Steud.; emergent plant in the Poaceae (grass) family
Derived from *phragma* (Greek: fence) and *australis* (Latin: southern) "southern plant with fence-like growth"

Invasive variety probably introduced from Europe to the Atlantic Coast in the late 1800s (non-invasive varieties are native)
Present throughout all states in the continental US

Introduction and spread

Phragmites (also called common reed) is a wetland species that grows from a thick, white, hollow root (rhizome) system buried deep in the substrate in areas with fresh to brackish water. The species

is distributed in temperate zones throughout the world and can be found on every continent except Antarctica. Phragmites is widely distributed in North America, occurring in all US states except Alaska, and in all Canadian provinces and territories except Nunavut and Yukon. Phragmites has been widespread in the northeastern US for many years and is currently spreading west into the Great Plains. Nebraska has initiated a multi-million dollar control program on the Platte River, where growth of phragmites is totally altering the aquatic ecosystem and causing problems for endangered birds (Chapter 4). There are many distinct genotypes (varieties) of phragmites, including at least two native varieties and a nonnative variety from Europe that is much more invasive than native varieties. The European variety was probably introduced to the Atlantic Coast in the late 1800s and has expanded its range throughout North America, most notably along the Atlantic Coast and in the Great Lakes area. The European variety has replaced native plants in New England and has become established in the southeastern US, where native phragmites has historically not occurred or has been present only in small populations. European phragmites sprouts, survives and grows better in fresh and saline environments than native phragmites. The species has been called an "ecosystem engineer" because numerous changes can occur when phragmites invades an area and replaces other vegetation. Large monotypic (single-variety) stands of European phragmites are associated with decreased plant diversity. In addition, soil properties, sedimentation rates, bird and fish habitat use and food webs may be altered when marshes are converted from diverse plant communities to dense, monotypic stands of phragmites.



Phragmites is most common in wet, muddy or flooded areas around ponds, marshes, lakes, springs, irrigation ditches and other waterways. The species persists during seasonal drought as well as frequent, prolonged flooding. Phragmites tolerates brackish and saline conditions, and the invasive European variety is better adapted to areas with higher salinity than are native varieties. The species grows best in sites with fresh to low brackish water (0 to 5,000 parts per million salinity), but can reportedly survive in areas with salinities equal to full strength ocean water (35,000 parts per million). Phragmites establishes and grows well on disturbed sites and is often considered a weedy or nuisance species. The species rapidly colonizes and forms monotypic populations in disturbed areas, but is slower to colonize and dominate in diverse vegetated wetlands. Phragmites grows best in full sun and is intolerant of shade.

Description of the species

Phragmites is a robust perennial grass that may reach 20 feet tall, but generally reaches a height of 10 to 12 feet. Maximum height is usually attained when plants are 5 to 8 years old. Phragmites spreads primarily by vegetative means via stolons and rhizomes and produces dense monotypic stands of clones, or plants that are genetically identical to one another. Clones are long-lived and can reportedly persist for over 1,000 years. Phragmites produces stout, erect, hollow above-ground stems from rhizomes that persist when stems and leaves die back during winter. Stems are usually unbranched and bear leaves that are arranged in an alternate manner along the top half of the stem. Leaf blades are blue-green to green in color and have margins that are somewhat rough. Leaves are flat at maturity and measure 4 to 20" long and 0.4 to 2" wide.

Reproduction

Phragmites reproduces sexually from seed, but most growth is from stolons (creeping aboveground stems) and rhizomes (underground stems). Stolons can grow to greater than 40 feet in length and are typically produced when water availability is low. Rhizome production and vegetative spread can be extensive and allow the species to spread into sites unsuitable for establishment from seeds. The species is often dispersed through the transport of rhizome fragments and the movement of soil or sod. Phragmites flowers are produced during mid-summer to fall and are borne in a large, feathery seed head that is 6 to 20" long. Seeds are dispersed by wind and water.

Problems associated with phragmites

Phragmites forms large monotypic stands that are virtually impenetrable. These stands replace diverse native plant communities and reduce plant, fish, bird and wildlife ecosystem productivity and diversity. However, phragmites does provide minor shade, nesting and cover habitat for mammals, waterfowl, song birds and fishes. Phragmites provides food as well as nesting, roosting and hunting habitats to a wide variety of bird species, including ducks (Chapter 3). In addition, waterfowl, pheasants and rabbits use the margins of stands of phragmites as cover to hide from predators. Some reports suggest that immature plants are readily eaten by goats, cattle and horses, but the species is not considered a high-value or highly palatable food for livestock or wildlife when plants are mature.

Habitat use by fish, crustaceans and other aquatic invertebrates can be affected by dense growth of phragmites. For example, small fish and crustaceans prefer habitats with smooth cordgrass (a shorter and less dense native species) to those with infestations of phragmites, and populations of aquatic invertebrates are generally highest in areas with other native vegetation such as cattail. Also, several studies report that marshes dominated by phragmites provide less suitable habitat for larvae and small juvenile forms of mud minnow.

Management options

As with any invasive aquatic plant, preventing the establishment of phragmites is the best available option. This can be challenging because native and European phragmites are almost indistinguishable from one another and identification of the varieties of phragmites can only be done by experts. The range of the invasive European variety of phragmites appears to have been expanded by the movement of equipment used in ditching, drainage and dredging operations. Inspection and cleaning of equipment should be part of the operator's general protocol before moving equipment into new areas to prevent the dispersal of any aquatic invasive plants, but particularly invasive varieties of phragmites.

The use of chemical, mechanical, physical and integrated control methods are acceptable tools for the control of phragmites. There are native populations of phragmites in some areas and managers may wish to go to the expense of determining whether their populations are native plants or the invasive European variety before treating the area. Positive identification of the invasive variety requires the use of genetic tools and DNA analyses, which are currently not readily available to the public. It may be desirable to maintain and encourage populations of native phragmites while discouraging populations of the invasive European variety. For example, phragmites can be useful for erosion prevention and bank stabilization and can actually increase the elevation of some areas by trapping sediments and building "land" from decomposed plant material and root mat formation each winter. Integrated management that employs multiple control methods may lead to the most efficient and economical control plan. Mechanical (Chapter 7) and physical (Chapter 6) controls (primarily mowing and burning) have been utilized for many years, but have provided varying degrees of success and usually result in temporary control at best. There are no biological control options available to control phragmites, although large herbivores such as goats have been used to control phragmites along the Platte River in Nebraska. In addition, herbicide control options are few and only recently have new herbicides that provide medium- to long-term control been identified and registered.

Because phragmites is an emergent plant that does not grow in deep water, some control has been noted in areas that are dredged to deepen the body of water to a minimum of five to six feet. This deepening removes plants and their rhizome systems and offers long term control. However, deepening is very expensive and eliminates desirable native plants as well. In addition, the permitting required to employ this control measure is tedious and difficult.

Burning – either alone or in combination with deep flooding or herbicides – has provided some level of success in some areas. Burning alone offers only a short-term solution, especially in wet areas, because this method does not effectively control the rhizome system and can actually stimulate rhizome growth that benefits from nutrients released during burning. A multi-stage process of burning followed by deep flooding or herbicide application after plants begin to regrow has been more successful. However, parameters such as the optimum depth of flooding required and the best stage of plant growth before herbicides can be applied are unclear. Also, the use of fire to control phragmites has become impractical in many locations and permits are sometimes difficult to obtain.

Managers of some impounded areas have flooded impoundments with high-salinity water and maintained flood conditions for an extended period of time. Partial control has been obtained using this method, but a minimum of half-strength seawater (18,000 parts per million) or higher is required. The use of high-salinity flooding is extremely site-specific. Also, the invasive European variety of phragmites is more tolerant of high salinity than are native phragmites.

No purposeful introductions of insects, pathogens or diseases have been attempted to control European or native phragmites to date. Several nonnative insect species have been accidentally brought into the country with European phragmites when it was used as packing material in shipments, but these do not appear to be viable biocontrol candidates. Livestock grazing (e.g., goats, cattle and horses) on young plants of phragmites reportedly provides some control of the species. However, the nutritional value of phragmites is only fair and the logistical and health aspects associated with managing livestock in marshy, wetland situations is extremely site-specific and generally impractical.

Herbicides currently labeled for control of phragmites in aquatic habitats are the systemic herbicides glyphosate, imazamox, imazapyr and triclopyr. Glyphosate and imazapyr are broad-spectrum herbicides that control both grasses and broadleaf plants, whereas imazamox and triclopyr are selective and cause damage only to certain groups of plants. The criteria for herbicide selection are site-specific and dependent on environmental conditions, growth stage of the plant, presence of desirable nontarget plant species in the area and alternate uses of the water such as drinking and irrigation (Chapter 11).

Several general application recommendations apply for any herbicide selected. The area to be treated should be drained if possible to allow the herbicide to contact as much of the plant as possible. Also, the maximum volume of water recommended on the label should be used for herbicide applications to ensure complete coverage of all leaves and stems. Deeply flooded areas should be treated at the highest herbicide rates allowed on the label. Because phragmites occurs in large, poorly accessible, expansive areas, aerial applications may offer the most efficient and economical method of application. Additional aerial application restrictions according to the specific herbicide labels must be followed.

Backpack sprayers can be used for small infestations and spot treatments. Plants should be carefully sprayed to wet, but runoff should be avoided. Herbicide labels list more specific instructions on herbicide mixing and use.

Summary

Phragmites is a widely distributed wetland species with both non-invasive native varieties and an invasive European variety in the US. The European variety has replaced native plants in New England and has become established in the southeastern US, where native phragmites has historically not occurred. The European variety of phragmites is more competitive than native varieties and sprouts, survives and grows better in fresh and saline environments than native phragmites. The invasive nature of European phragmites results in large monotypic populations of the species, which are associated with decreased plant diversity and changes to the ecosystem that include alterations of soil properties, sedimentation rates, bird and fish habitat use and food webs. A variety of methods can be used to provide varying levels of control of invasive phragmites and the greatest success is realized when a number of different methods are employed in an integrated program. However, control of the invasive European variety of phragmites is made more challenging by the presence of the native non-invasive varieties, which can be a desirable part of aquatic ecosystems.

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Photo and illustration credits:

Page 171: Common reed; Ann Murray, University of Florida Center for Aquatic and Invasive Plants
Page 172: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 174: Common reed; Ann Murray, University of Florida Center for Aquatic and Invasive Plants

Chapter 15.12: Purple Loosestrife

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Lythrum salicaria L.; erect, emergent perennial herb in the Lythraceae (loosestrife) family
Derived from *lythrum* (Greek: blood) and *salicaria* (Latin: willow-like) "plant that stops blood and is willow-like"

Introduced from Europe to the east coast of North America in the early 1800s
Present in every state throughout the US except for Florida, and found in all Canadian provinces

Introduction and spread

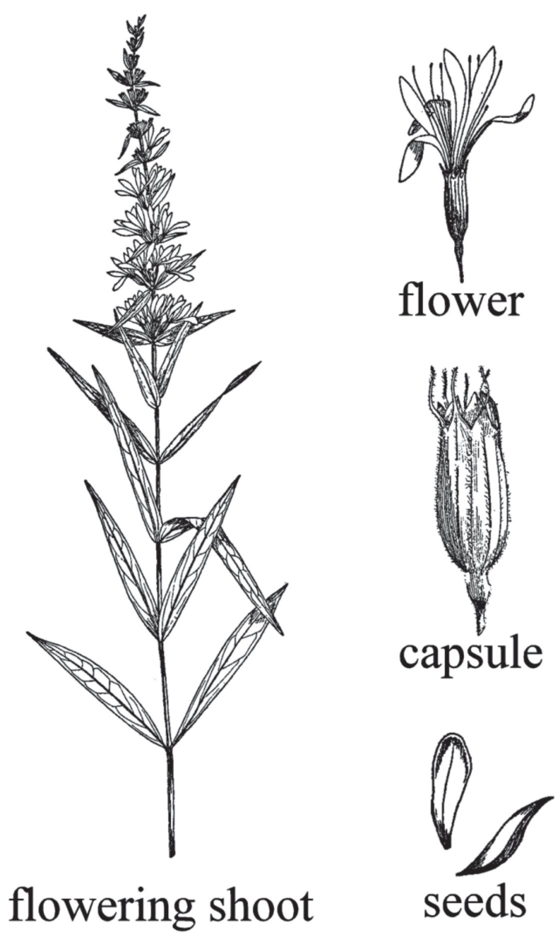
Lythrum salicaria L. (purple loosestrife) is often referred to as "the purple plague" in North America and is native to Europe and Asia. Purple loosestrife is an aggressive invasive plant that was deliberately introduced to the eastern coast of North America in the early 1800s. Settlers of the region valued the plant as an ornamental for perennial gardens and used the species as a medicinal herb to treat dysentery, diarrhea, bleeding and ulcers. The honey trade also increased regional seed propagation of the plant because it was favored as bee forage. In addition, European ships contributed to the spread of purple loosestrife by releasing ballast water and delivering shipments of wool that contained seeds of the species. By the 1830s, purple loosestrife had become established along the New England seaboard and the range of the species further expanded throughout New York State and the St. Lawrence River Valley through inland canals constructed in the late 1880s. As road systems expanded and commercial distribution of the plant by the nursery trade increased, purple loosestrife spread westward and southward and can now be found in every state and province of the US and Canada, except for Florida. Purple loosestrife grows in most freshwater wetlands but also tolerates a wide range of environmental conditions and can spread to both tidal and non-tidal brackish waters.

Description of the species

Purple loosestrife is an erect, emergent perennial dicot herb with a dense, bushy appearance. The species tolerates a wide range of wetland environments and grows in habitats ranging from pastures with moist soil to sites with shallow water such as marshes and lakeshores. Established plants can tolerate a variety of soil conditions, including soils that are dry or permanently flooded and soils that are low in nutrients and pH. In addition, plants can grow in rock crevasses, on gravel, sand, clay or organic soils. Purple loosestrife can grow from four to ten feet in height and has a dense canopy of stems that emerge from its wide-topped crown. Each plant produces as many as 50 square, hard, red to purple stems that arise from a single root mass. Leaves are 1-1/2 to 4" long and 2/10 to 6/10" wide and are lance-shaped, stalk-less, heart-shaped or rounded at the base and borne in an opposite or whorled arrangement. Purple loosestrife produces flowers with magenta, purple, pink or white petals that are 4/10 to 8/10" long. The species blooms throughout most of the summer, which adds to its appeal as an ornamental plant and as a favorite of beekeepers. The reddish-brown seeds are very small (1/25" long) and are often produced during the first growing season. Purple loosestrife is often confused with a number of plants with spikes of purple flowers, including gayfeather (*Liatris pycnostachya*), blue vervain (*Verbena hastata*) and fireweed (*Epilobium angustifolium*). However, the species most closely resembles the native winged loosestrife (*Lythrum alatum*) and *Lythrum virgatum* L., a nonnative cultivated purple loosestrife. *L. virgatum* is very similar to purple loosestrife in appearance and was formerly classified as a separate species, but is now considered by some to be a subspecies or variant form of purple loosestrife.

Reproduction

The extended flowering season of purple loosestrife typically lasts from June to September and allows each plant to produce as many as 3 million seeds each year. Long-tongued insects, including bees and butterflies, serve as pollinators. Seeds are dispersed by water and can "hitchhike" in mud that adheres to wildlife, livestock and people. Seed survival can be as high as 60 to 70%, which produces a sizeable seedbank in only a few years. Germination occurs in open, wet soils as temperatures increase in the spring, but seeds can remain dormant and viable for many years in the soil. In addition, submersed seeds can survive for up to 20 months in flooded conditions. Purple loosestrife readily colonizes newly disturbed areas because of its high production of viable seeds with multiple modes of dispersal. Disturbed areas with exposed soil are most vulnerable to invasion and rapid colonization by purple loosestrife because these sites provide ideal conditions for seed germination and usually lack native plants that compete with the weed for resources. Purple loosestrife spreads predominately via seed dispersal, but can also spread vegetatively by producing new shoots and roots from clipped, trampled or buried plants. Purple loosestrife's ability to reproduce via vegetative means is especially important when adopting management strategies because mechanical or physical control efforts can inadvertently spread harvested plant fragments and create new infestation sites. In addition, disturbances in the form of changes in water levels



from drought or a planned water drawdown provide ideal conditions for maximum seed germination and growth.

Problems associated with purple loosestrife

Purple loosestrife aggressively invades many types of wetlands, including freshwater wet meadows, tidal and non-tidal marshes, river and stream banks, pond edges, reservoirs and roadside ditches. The formation of dense, monotypic stands of purple loosestrife suppresses native plant species, decreases biodiversity and leads to a change in the wetland's community structure and hydrological functioning, while eliminating open water habitat in many locations. Around 200,000 acres of wetlands are lost in the US every year due to invasions of purple loosestrife and as much as 45 to $50 million per year is spent on efforts to control the growth of this species. In addition to funds spent on control efforts, economic losses to agriculture can exceed millions of dollars annually when purple loosestrife invades irrigation systems. Also, entire crops of wild rice may be lost when this species invades shallow lakes and bays dominated by wild rice, which results in great economic loss to agricultural communities.

Purple loosestrife alters the physical makeup of a wetland, but the species can change the chemical properties of the wetland as well. For example, leaves of purple loosestrife decompose rapidly after being shed in the fall and the nutrients released during decomposition are quickly flushed out of the wetland. In contrast, the vegetation of native species does not fully decompose until the following spring and nutrients are maintained in the wetland throughout the fall and winter. This difference in the timing of nutrient release means that wetland decomposers have fewer nutrients available to subsidize peak population growth in the spring, which alters the structure of the food web. The effects of altered water chemistry extend to many fauna in aquatic ecosystems as well. For example, chemicals released during the decomposition of purple loosestrife leaves can slow the development of certain frog tadpoles, which decreases the frog's chance of surviving its first winter. Recent research at Cornell University suggests that threats to amphibians by nonnative plants may be underestimated. Their data indicate that organisms that breathe through gills (especially *Bufo americanus*, the American toad) are sensitive to the high concentration of tannins naturally produced during purple loosestrife decomposition.

Purple loosestrife further affects the wildlife communities of wetlands through a variety of other means. The species is a very poor food source for herbivores and crowds out species that are more beneficial to the wetland food web. As a result, stands of purple loosestrife can jeopardize threatened and endangered plants and wildlife, especially in the northern US. For example, the bog turtle has lost extensive basking and breeding habitat due to the introduction of this aggressive plant. Purple loosestrife also displaces native plants such as cattail and bulrush, which provide high quality habitat to numerous nesting birds and aquatic furbearers. Wetland specialists such as the marsh wren or least bittern (Chapter 4) prefer sturdy nesting sites such as cattail-dominated wetlands and are unable to utilize purple loosestrife for their nests. Also, muskrat, beaver and waterfowl prefer cattail marshes and are more able to utilize these sites that are dominated by native plants as compared to dense, monotypic populations of purple loosestrife.

A primary problem associated with purple loosestrife is its attractiveness. European immigrants to the US deliberately imported purple loosestrife as an ornamental plant in the 1800s and homeowners still actively plant the species today. Purple loosestrife may add a welcome burst of color to an otherwise dull private garden or pond, but the adaptability and aggressiveness of this plant can quickly wreak havoc on the unsuspecting homeowner's backyard. The sale or distribution of purple loosestrife is illegal in many states; however, nurseries and greenhouses sell the plant in many areas across the country and it continues to be included in some seed mixes. Consumers should always read seed package labels before purchasing in order to ensure that this aggressive nonnative plant is not included in the mix.

Management options

The best way to stop an invasion of purple loosestrife is to be aware of pioneering plants and small isolated colonies. In these cases, hand removal of small, isolated stands is an effective preventative control method. The use of physical (Chapter 6) and mechanical (Chapter 7) control methods may provide annual control of low-density invasions and can include water level manipulation, hand removal, cutting and burning. When using these methods, treatment must be completed before seeds are produced to avoid seed dispersal and contributions to the seed bank. It is also essential to remove roots from the soil since plants will regrow from broken roots or root fragments. Removal of flowering spikes will prevent seed formation and cutting or harvesting stems at the ground level will inhibit growth temporarily. While these methods temporarily halt growth, they should be used in conjunction with herbicides or biological control agents to provide longer-term management.

Annual applications of herbicides (Chapter 11) can be effective and can provide relatively successful season-long control of purple loosestrife stands. Control rates of > 90% can be accomplished with applications of the herbicides 2,4–D, glyphosate, triclopyr, imazapyr and imazamox. Single applications of registered herbicides generally do not provide satisfactory control of loosestrife for more than one season. Multi- season control of purple loosestrife can be achieved using imazapyr; however, the rates required for this level of control often have a negative impact on desirable vegetation, which limits its use. Herbicides used to control purple loosestrife have very different selectivity spectrums for nontarget plants. In addition, application rate affects selectivity. When selecting a herbicide for management of purple loosestrife, it is important to consider the impact of the herbicide on the many important nontarget wetland species that may be affected by overspray or exposure to high concentrations of herbicides needed to effectively control purple loosestrife. In addition, readers should be aware that most states require application permits before herbicides can be used for management of purple loosestrife in wetlands or other aquatic locations.

The vast seedbank in the soil of established stands of purple loosestrife facilitates regrowth of the species after herbicides dissipate and are no longer effective. Therefore, the most effective long-term option for suppressing and controlling the growth of this invasive weed may be the use of biological control (Chapters 8 and 9). Research and evaluation of potential biological control agents for the

North American purple loosestrife invasion identified a number of European insects that showed promise as biocontrol agents. The USDA-APHIS has now approved five European insect species for introduction as classical biocontrol agents. These include two leaf-feeding beetles [*Galerucella calmariensis* L. and *G. pusilla* Duftschmidt (Coleoptera: Chrysomelidae)], a root-mining weevil [*Hylobius transversovittatus* Goeze (Coleoptera: Curculionidae)] and a flower-feeding weevil [*Nanophyes marmoratus* Goeze (Coleoptera: Curculionidae)]. The fifth insect approved was the seed-feeding weevil *Nanophyes brevis* Boheman (Coleoptera: Curculionidae), but this insect was ultimately not introduced due to problems obtaining healthy, parasite-free insects from Europe. Initial releases of the leaf-feeding beetles *Galerucella* spp. and the root-mining weevil *Hylobius* sp. into natural areas from New York to Oregon were experimental and early observations suggested that the leaf-feeding beetles occasionally feed on native plant species; however, this now appears to be of little consequence.

G. calmariensis and *G. pusilla* are leaf-feeding beetles easily confused with native North American *Galerucella* species. The European species, however, seriously affect purple loosestrife growth and seed production by feeding on the leaves and new shoot growth. The two introduced beetles are similar in appearance and share similar life history characteristics. Adults overwinter in leaf litter and emerge in the spring shortly after shoot growth begins. Peak dispersal of overwintered beetles occurs during the first few weeks of spring, when new-generation beetles make dispersal flights shortly after emergence and can locate host patches greater than a half mile away within only a few days. Adults feed on shoot tips and females lay 2 to 10 eggs on the leaves and stems of purple loosestrife from May to July. Young larvae feed on developing leaf buds, while older larvae feed on all aboveground plant parts. Pupation by mature larvae takes place in the litter below the plant. Reports from several locations describe complete defoliation of large multi-acre stands of purple loosestrife, with local biomass reductions of greater than 95%. These results are limited and localized, but have occurred in states ranging from Connecticut to Minnesota and into the provinces of Canada to date.

Larvae of the introduced root-boring weevil *H. transversovittatus* hatch and feed on root tissue for one to two years depending on environmental conditions. Pupation occurs in the upper part of the root, with adults emerging between June and October. Adults then feed on foliage and stem tissue and can live for several years. The root-boring weevil can survive in all potential purple loosestrife habitats, except for permanently flooded sites. Adults and larvae can survive extended submergence, depending on the temperature, but excessive flooding prevents access to plants by adults and eventually kills developing larvae. Feeding by adults has little effect on the plants, but as is typical, feeding by larvae can be very destructive to the rootstock.

The flower-eating weevil *N. marmoratus* has been introduced to several states and is widespread in Europe and Asia, where it is able to tolerate a wide range of environmental conditions. The flower-eating weevil severely reduces seed production of purple loosestrife as larvae consume the flower and mature larvae form a pupation chamber at the bottom of the bud. Damaged buds do not flower and are later aborted, thus reducing purple loosestrife seed output. New-generation beetles appear mainly in August and feed on the remaining green leaves of purple loosestrife. Adults overwinter in leaf litter; development from egg to adult takes about 1 month and there is one generation per year.

Summary

The introduction of purple loosestrife into North America occurred in the early 1800s with the importation of wool containing seeds, as a favorite herb in flower gardens and from released ship ballast water. Unfortunately, this attractive plant has become one of North America's most widely dispersed and dominant nonnatives in habitats ranging from dry soils to inundated marsh areas or lakes. Stems can grow as tall as 10 feet and can form densities of up to 50 stems per plant, creating a canopy that limits light and space to native plants. Purple loosestrife causes problems in wetland ecosystems by forming dense monocultures, outcompeting native plants, altering hydrology and changing water chemistry, which all in turn affect native plant and animal communities. Purple loosestrife is an easily identified emergent plant, which facilitates hand removal and selective herbicide applications. These methods can provide temporary control of small populations, but access to the species is often limited. Populations are most effectively controlled when multiple control methods are used in conjunction, but biocontrol seems to provide the best long-term suppression of dense stands of purple loosestrife. Fortunately, classical biocontrol agents appear to be able to successfully reduce populations of purple loosestrife throughout North America.

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Photo and illustration credits:

Page 177: Purple loosestrife; Bernd Blossey
Page 178: Line drawing; adapted from Muenscher (1967)
Page 180: Mating pair of the leaf-feeding beetle *Galerucella calmariensis*, Bernd Blossey
Page 181: Adult root-boring weevil *Hylobius transversovittatus*, Bernd Blossey

Chapter 15.13: Flowering Rush

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Butomus umbellatus L; emergent shoreline plant in its own family, Butomaceae (flowering rush); originally placed in the Alismaceae (water-plantain) family

Derived from *bous* (Greek: ox) and *temno* (Greek: "I cut"), referring to its sword-like leaves with sharp edges that cut the mouths of cattle feeding on the species

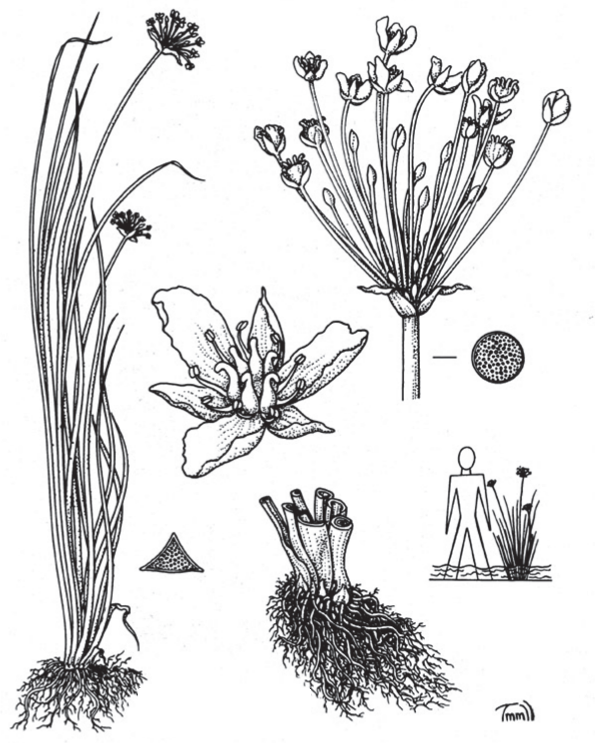
First identified along the St. Lawrence River in Quebec in 1897; likely introduced from Europe as a garden plant

Present in the northern US from Idaho to Maine and in the adjacent Canadian provinces

Introduction and spread

Flowering rush (*Butomus umbellatus* L.) is native to Europe and Asia. It is thought that the species was first introduced to the US for use in ornamental gardens, but flowering rush thrives along shallow shorelines and in wetlands. The first observation of the species in North America occurred along the St. Lawrence River in Quebec in 1897 and botanists believe that multiple introductions have occurred since that time. By the mid 1950s, flowering rush populations were documented throughout the Great Lakes Region. Populations of flowering rush in the Great Lakes and points west are believed to be of European origin, whereas populations in the St. Lawrence River area are thought to be from Asia. Since the 1950s, flowering rush has spread to the west, north and east of the Great Lakes, with populations now found across the northern US and extending from Washington to Maine and nearly all of the adjacent Canadian provinces. Flowering rush tolerates a wide variety of shallow water and wetland settings and often forms dense stands that displace native riparian species, degrade fish and wildlife habitat, alter hydrologic patterns and interfere with recreational use of water bodies.

Description of the species



Flowering rush is a perennial monocot herb that can reach up to 5 feet in height and tolerates a wide variety of riparian and wetland habitats. Plants have an extensive rhizome and root system and soil type or consistency and soil pH do not appear to affect growth. However, the species cannot grow in shade and is intolerant of saline or brackish waters. Plants become established in wet areas or along the shallow margins of lakes, ponds and streams and can grow into water up to 9 feet deep. Leaves of flowering rush are fleshy, thin and sword-like and resemble those of native bulrush (*Sparganium* spp.), but are triangular in cross-section. Submersed leaves remain limp or float on the surface of the water, whereas emergent leaves can reach to 3 feet in length and may have tips that are twisted in a spiral manner. Flowering rush is easiest to identify when it is flowering, which only occurs if plants are growing in very shallow water or along the shoreline. Plants flower between June and August, depending on temperature and latitude. The flowers are borne in an umbrella-shaped cluster (umbel). Individual flowers have three petals that are white to pink to purple in color.

Reproduction

Flowering rush is dispersed in four ways: seeds, vegetative bulblets produced on the inflorescence at the base of flower stalks, vegetative bulblets that form along the sides of rhizomes (underground stems with nodes that produce new shoots and roots), and rhizome fragments. Once established, the species expands its population size and spreads locally by rhizome elongation. Both seeds and bulblets can be transported by water currents and are long-lived, which facilitates their dispersal by wildlife, boaters and other human activities.

Eastern US populations of flowering rush are reportedly fertile diploids (with 2 sets of chromosomes), whereas sterile triploid populations (with 3 sets of chromosomes) occur in western North America. Diploid populations flower prolifically and produce both seeds and bulblets and their spread is due to dispersal of seeds and bulblets. Triploid populations in the West rarely flower and produce low numbers of seeds and bulblets. As a result, the majority of the spread of western populations is due to rhizome fragmentation, which results in clonal (genetically identical) populations.

Problems associated with flowering rush

Flowering rush can form dense infestations that compete with native riparian species and displace more desirable plants. Dense growth of the species may also allow it to outcompete threatened or endangered plant species and likely alters wildlife habitats. There are varying levels of concern about the impact of flowering rush on wetlands and fresh water habitats. For example, reports from the St. Lawrence River suggest that even high densities of flowering rush have not significantly reduced plant diversity. However, displacement of native plant species and the potential for wildlife habitat alteration make flowering rush a species of concern.

The impacts of flowering rush to water use and access may be more significant. For example, flowering rush has developed extensive monotypic populations in reservoirs with widely varying water levels in western states. The species is also currently causing economic impacts in irrigation canals and drainage ditches in the western US and large populations of flowering rush impede access to shallow lakes by colonizing shoreline areas where aquatic plants have not grown in the past. Marshlands are becoming dominated by flowering rush because the species thrives in areas with fluctuating water levels and expansion throughout littoral zones interferes with shoreline access, boating and fishing.

Management options

Unlike many other invasive species, there is not a wealth of information regarding the management of flowering rush infestations in North America. However, the same management philosophies hold true – early detection of introductions and rapid response to new infestations provide the most effective control of flowering rush and limit further spread of the species. Flowering rush resembles many native species; therefore, accurate identification of the species is critical before initiating management efforts to avoid damaging nontarget desirable native plants.

Manual control methods include cutting and hand digging (Chapter 6). Cutting will not kill flowering rush because the species will produce new growth from underground roots and rhizomes, but this method may decrease abundance and prevent seed and bulblet production by removing inflorescences. Plants should be cut below the water surface and care should be taken to remove all cut plant parts from the water. Multiple cuts may be required throughout the summer to provide adequate control and to prevent the formation of flowers, seeds and bulblets. Hand digging is useful only when managing individual plants or small infestations. The entire root structure must be carefully removed because fragments of roots, rhizomes or bulblets left in the sediment can rapidly regrow. All plant parts removed during cutting or hand digging must be taken out of the water and transported well away from water or wetland areas to prevent recolonization.

The use of herbicides to control flowering rush is challenging due to the limited foliage available for herbicide coverage and uptake. Often only a small part of the plant emerges above the water and foliar herbicide coverage is so limited that herbicides are generally not very effective. The best time to apply foliar herbicides is likely during periods when water levels are low to improve herbicide coverage. There is no product that is selective for flowering rush and controls the species without the potential for harming other plants, so care must be taken during herbicide application to avoid impacts to nontarget species. Research by the Minnesota Department of Natural Resources suggests that a mid-summer treatment with imazapyr may be effective and research on management of this invasive weed is ongoing.

Summary

Flowering rush is an invasive species that has steadily expanded its range across the northern US and the Canadian provinces. It closely resembles bulrush and other native species and is difficult to identify unless it is flowering. The species employs multiple reproductive strategies that have helped to expand its range over the past 50 years. All the potential impacts of this invasive species on aquatic systems are not yet known, but flowering rush is capable of abundant growth that can displace native species and alter habitats. Also, dense shoreline growth of the species can certainly interfere with access and recreational uses of infested water bodies. There is limited information available regarding the management of flowering rush, but as with other invasive species, early detection and rapid response are paramount to successfully controlling new infestations. Cutting below the water surface, careful hand-digging and selective treatment with herbicides are currently the most effective strategies to control infestations of flowering rush. The expansion of flowering rush has occurred primarily in the western US and it is difficult to predict how extensive the problem may become, but research is underway to investigate the biology of the species and to identify management options that may be useful to control the spread of flowering rush.

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Photo and illustration credits:

Page 183: Flowering rush; Thomas Woolf, Idaho State Department of Agriculture
Page 184: Line drawing; University of Florida Center for Aquatic and Invasive Plants
Page 185: Flowering rush; Thomas Woolf, Idaho State Department of Agriculture

Appendix A: Requirements for Registration of Aquatic Herbicides

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History of pesticide regulation

A pesticide is defined as any product that claims to control, kill or change the behavior of a pest. The United States first started regulating pesticides in 1910. The 1910 Federal Insecticide Act was intended to protect farmers from adulterated products and false labeling claims. With the continuous increase in pesticide development and use after World War II, Congress passed the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) in 1947. This act, which would be amended through the years, required that all pesticides be registered with the Department of Agriculture before they could be shipped in interstate commerce. The same federal agency responsible for agricultural production in the United States was now responsible for the regulation of pesticides on agricultural crops. FIFRA established procedures for the registration and labeling of pesticides, but dealt mainly with the efficacy or effectiveness of pesticides and did not regulate pesticide use. Almost anyone could use a pesticide for any purpose and there was no legal recourse if a pesticide was not properly used. In addition, FIFRA did not allow for the denial of a pesticide registration request.

In 1962 Rachel Carson published "Silent Spring," which drew widespread public attention to the indiscriminate use of pesticides with unknown human health and environmental effects. Many of the pesticides were persistent in the environment and were transferred from one animal to the next upon being eaten (a phenomenon known as bioaccumulation). As a result, some pesticides were ultimately ingested by humans and other nontarget animals, including wildlife. Very little was known at the time about the fate of pesticides in the environment and the potential effects of their residues on man and wildlife.

The Environmental Protection Agency (EPA) was created in 1970 and the responsibility for regulating pesticide use and labeling was transferred from the USDA to this new agency. This marked the beginning of a shift in the focus of federal policy from the control of pesticides for reasonably safe use in agricultural production to the control of pesticides for the reduction of unreasonable risks to man and the environment. In 1972 Congress passed the Federal Environmental Pesticide Control Act, which amended FIFRA and set up the basic American system of pesticide regulation to protect applicators, consumers and the environment that we have today. This Act gave the EPA greater authority over pesticide manufacturing, distribution, shipment, registration and use. EPA could now, among other things:

1) require additional data as necessary;
2) suspend or cancel the registration of existing pesticides;
3) prohibit the use of any registered pesticide in a manner inconsistent with label instructions;
4) require that pesticides be classified for specific uses;
5) deny a registration request;

6) provide penalties (fines and jail terms) for violations of FIFRA;
7) provide states with the authority to regulate the sale or use of any federally registered pesticides in that state as long as state rules were at least as strict as federal guidelines.

In 1988 Congress once again amended FIFRA by requiring the EPA to reregister all pesticides registered before November 1984 and to ensure that the database was current and in accordance with modern science. The development of the Food Quality Protection Act (FQPA) in 1996 amended both the FIFRA and the Federal Food, Drug, and Cosmetic Act (FFDCA). This Act set a single health-based standard for residues of pesticides in food and required the EPA to reevaluate all tolerances for pesticides and their inert ingredients.

Registration

Pesticide regulations are continuously under review and revision as scientific methods and knowledge increase. The following sections of this chapter will discuss pesticide registration and enforcement of pesticide laws, which are just a portion of the EPA's overall responsibility to protect the environment. It costs 30 to $60 million or more, and 8 to 10 years, to introduce a new pesticide to the market. Pesticides that are destined for use in aquatic systems in the US must be registered by the federal government through the EPA and by the state in which the pesticide will be used. The product may only be used in accordance with the label accepted by the EPA and any other applicable state regulations as long as the state regulations are at least as restrictive as the federal label. A pesticide may occasionally be registered by a state based on a special local need. In such circumstances, the active ingredient of the pesticide must be registered by the EPA and the appropriate tolerances in fish, shellfish and irrigated crops must be established by the EPA. This federal agency has overall responsibility for pesticide regulation even in states with small but locally important pest control needs.

The burden of proof to show that a pesticide will not cause unreasonable adverse effects on man and the environment rests with the registrant (the company that develops or labels the pesticide). The registrant is responsible for testing the active ingredient and the end use product (the final formulated product offered for sale) for potential harm to man and the environment. The EPA requires between 84 and 124 different studies to satisfy this requirement. These studies include toxicity and exposure tests on laboratory animals that measure the possible effects of the pesticide on human health – to applicators and to the general public – through direct exposure and through residues in food. These studies also determine the fate of the pesticide once it is introduced into the environment and the effect of the pesticide on nontarget organisms. The EPA reviews these studies and determines the appropriate labeling for the use of each pesticide.

Label precautions may include user safety information (protective clothing, reentry intervals or specific hazards), environmental safety warnings, container disposal and pesticide classification. In addition, all labels must provide appropriate directions for use (see "Pesticide Labeling" below).

The EPA regulates pesticide use from occupational (applicator/worker), residential and dietary standpoints and determines the potential effects of acute (immediate), intermediate and chronic (long term) exposure to humans. If the use of a pesticide results in a residue of the pesticide in food or feed, it is necessary to establish a tolerance level for that pesticide under the FFDCA. The EPA also evaluates residues in drinking water and must determine whether pesticide residue levels found in drinking water, fish, shellfish and any other food or feedstock meet the safety standard of the FQPA. In short, the EPA verifies that there is a reasonable certainty that no harm will result from the residues of the pesticide in food or feed. The FQPA is a risk-based statute and does not provide for the analysis of risks vs. benefits. Examples of some of the studies required before a product can be used as a pesticide are listed below. More detailed information is available at: http://www.epa.gov/lawsregs/search/40cfr.html. Click on "Chapter I"; then under "Browse Parts" click "150 – 189"; and finally under "Table of Contents" click "158.1 to 158.2300."

Toxicity studies (how dangerous is the pesticide to humans?)

•Acute toxicity: study the immediate effects of exposure to determine appropriate user precautions
•Sub-chronic toxicity: examine intermediate toxicological effects to identify the risks of less than lifetime exposure
•Chronic toxicity: evaluate long-term toxicity effects to determine possible problems associated with a lifetime of exposure
•Oncogenicity: determine whether the product causes cancer
•Developmental and reproductive toxicity: identify any effects on development and reproductive function

Chemistry studies (what is the pesticide?)

•Chemical identity, physical and chemical properties
•Disclosure of manufacturing process and all inert ingredients
•Determine chemicals of concern including the active pesticide and inert components
•Develop analytical methods for determining concentrations of the pesticide in plants, soil, water and food
•Determine the amount of pesticide left on plants, soil, water and food as a result of use

Environmental fate (what happens to the pesticide after it has been applied?)

•Hydrolysis: establish the significance of chemical breakdown in water
•Photolysis: determine the interaction of the pesticide with light
•Degradation: determine when the pesticide breaks down and what it breaks down to in water, soil and air
•Metabolism: examine the breakdown of the pesticide by organisms in the soil and water
•Mobility and bioaccumulation: determine how the pesticide moves in the environment and whether it accumulates up the food chain
•Field dissipation: test and monitor how the pesticide behaves under realistic conditions

Ecological toxicity (how dangerous is the pesticide to fish, birds, mammals and plants?)

•Acute toxicity: study the immediate effects on wildlife
•Chronic dietary toxicity: examine the effects of a lifetime of exposure in birds
•Reproduction studies
•Toxicity to plants

Because the EPA relies on data submitted by the registrant, it carries out a laboratory audit program. This program sends EPA scientists and enforcement personnel to laboratories that conduct studies on pesticides. These personnel are responsible for reviewing the testing procedures to ensure that they are carried out in accordance with EPA regulations for conducting good laboratory studies. In addition, the EPA requires the registrant to submit to them any data concerning adverse effects associated with the use or new testing of the chemical. These data are immediately reviewed by the EPA and any corrective action (label changes, use deletions or product cancellation) is taken as deemed necessary by the agency.

Tolerances

A tolerance is a residue level established by regulation which is considered a "safe level" of a pesticide and it is also an enforceable level. An "enforceable level" essentially means that when a pesticide is found in or on a food product and is either (1) not registered for use on that food product, or (2) present at a level higher than the tolerance established for that food crop, the food crop may be destroyed and investigations must be conducted to determine whether fines or other penalties are warranted. The tolerance is based on acute and chronic animal toxicity data. These data are multiplied by a 100-fold safety factor to determine an allowable residue level. The EPA does not set tolerances in drinking water as a result of pesticide use, but it does assess the safety of drinking water using the same safety standard for water as it does for food or feed before it will register the pesticide. Under the FFDCA as amended by the FQPA in 1996, a tolerance may only be established when the EPA determines that there is a reasonable certainty that no harm will result from the aggregate exposure (food, water and residential exposure) to the active ingredient and the inert ingredients in the pesticide.

Pesticides that are registered for use in a way that results in residues of the pesticide or its metabolites of concern in or on food or feed require the establishment of a tolerance under the FFDCA. Tolerances for pesticides are established under the FFDCA by the EPA. Food or feed contaminated with residues of pesticides or their metabolites of concern that do not have an established tolerance or have residues above the established tolerance level are considered adulterated and may be seized and destroyed by the Food and Drug Administration (FDA). While the EPA sets these pesticide tolerances, the FDA is responsible for enforcing them. Pesticides to be used in aquatic systems must have established tolerance levels of that pesticide and its metabolites of concern in fish, shellfish and any crops that would be irrigated with treated water.

Pesticide labeling

Pesticides are classified as either "general use", which can be purchased and used by anyone, or "restricted use", which may only be sold to and used by persons under the direct supervision of a certified applicator. A certified applicator must complete the appropriate federal or state training and testing. Pesticides can be used to control nuisance aquatic weeds without causing unreasonable adverse effects to man or the environment as long as label directions, precautions and warnings are followed.

The EPA regulates pesticides through pesticide labeling and determines the appropriate minimal label information required for the safe and effective use of the pesticide based on data submitted by the registrant. All labels must also include certain information; for example, all labels must carry several specific statements including "Keep Out of Reach of Children" and a signal word (Caution, Warning or Danger). Directions for use – including application rates, number of applications allowed per season, user precautions, environmental precautions, container disposal instructions and other directions as determined by the EPA – are also required. In addition, every label must carry the statement "It is a violation of Federal law to use this product in a manner inconsistent with its labeling." This means the pesticide can only be used in accordance with the label on the product container. The EPA stamps the label as accepted and this is the only label the registrant may place on its pesticide container before selling the product to the public. This label then becomes the principal communication between the registrant and the user. The directions for use, precautions and warnings tell the user how to use the pesticide and what precautions to take when the pesticide is used. Any changes to the labeling must be submitted to and approved by the EPA prior to marketing. For a full discussion on labeling requirements, please visit the EPA website on labeling at http://www.epa.gov/oppfead1/labeling/lrm/

Review of registered pesticides

In 2008 the EPA completed its reregistration of all pesticides registered prior to November 1984 as required by the 1988 amendment to FIFRA. This effort took over 20 years as it required the reassessment of all products and their associated tolerances. In 2008 the EPA also initiated a Registration Review Program. This program, required by the 1996 amendments to FIFRA (FQPA), will review the registration of all registered pesticides on a continual 15-year cycle to ensure that pesticides remain in compliance with developing changes in science, public policy and pesticide use practices. For more information about the Registration Review Program go to http://www.epa.gov/oppsrrd1/registration_review/highlights.htm

Enforcement

To ensure compliance with the requirements of FIFRA, federal agents and state inspectors monitor the marketplace and conduct inspections and investigations at establishments where pesticides are produced and distributed and at facilities of commercial and private applicators where pesticides are stored. While all enforcement efforts are important, use-related inspections and investigations provide ongoing feedback to the EPA regarding the effectiveness of label requirements and accepted directions for use. This information, coupled with the requirement that registrants report all unanticipated adverse effects encountered as part of the distribution, sale and use of a pesticide, provides an impetus for additional data requirements. Mandatory label modifications may also be ordered depending on the nature of the data received.

It is a violation of federal law for any person to use any registered pesticide in a manner inconsistent with label directions. The directions can cover all aspects of the pesticide, including transportation, storage, mixing, loading, application rates, target pests, use sites or crops, methods of application, personal and worker protection, environmental warnings, disposal and anything else necessary to protect human health or the environment. Federal and state inspectors conduct both routine facility inspections and "for cause" use investigations. Evidence of misuse (e.g., samples, photos, statements and records) may be used to prosecute violators in federal or state jurisdictions (or in both) depending on the circumstances of the case. Penalties can be substantial. For example, FIFRA provides for a $6500 civil/administrative fine for each violation or count. In addition, criminal prosecutions are not unusual. While classified as misdemeanors, criminal offenses under FIFRA are considered serious environmental crimes and carry a maximum penalty of one year in jail per count. Two unlicensed pest control operators in Mississippi were sentenced to 5.5 and 6.5 years in a federal penitentiary. Sentences of 2 to 3 years for misuse of pesticides are commonplace, along with substantial fines. However, pesticide violations have decreased over the last two decades as education and knowledge of pesticide laws and regulations have become better known.

Good laboratory practices (GLP)

Working closely with the Office of Pesticides Programs, teams of investigators and scientists regularly conduct Good Laboratory Practices inspections at facilities that generate the scientific studies used in support of pesticide registrations. In addition, specific studies are randomly audited to verify adherence to identified protocols and procedures. Everything from the credentials of the researchers to the calibration of the equipment is thoroughly examined. The raw data are compared to the reported results to ensure accurate reporting. "For cause" audits of data are conducted when EPA scientists observe inconsistencies or irregularities in the studies submitted by the registrants.

A fair and vigorous enforcement program levels the playing field for the regulated community, removes any economic advantage of noncompliance (such as when using an unregistered pesticide on a site or crop not listed on the label) and exacts retribution as appropriate. As a result, enforcement is the exclamation point of the process that began with the registration of pesticides and the development of the labels and completes the mission of the EPA to provide a measure of consumer protection and to protect human health and the environment.

Summary

The US Environmental Protection Agency was formed in 1970 and became responsible for regulating the rapidly expanding development and use of pesticides. During the course of the next 20 years, the use of some pesticides was cancelled and testing requirements were developed to study the effects of pesticides on human health and the environment. These requirements are regularly revised to include the most recent developments in science. EPA toxicologists, chemists and biologists review proposed pesticide labels and revise label instructions as needed to ensure that human health and environmental safety will not be compromised. States may also register or approve pesticide labels for use in their jurisdictions and are allowed to add additional restrictions or requirements to the pesticide label. However, state guidelines cannot be less restrictive than those outlined on the federally approved label. The EPA and state regulatory agencies enforce pesticide laws regarding the purchase, use and disposal of pesticides. Pesticide labels are developed after years of research and include specific information about the pesticide and its use. The label is a legal document and all directions must be followed by those who use the product.

Photo and illustration credits:

Page 188: Herbicide testing; William Haller, University of Florida Center for Aquatic and Invasive Plants

Appendix B: Aquatic Herbicide Application Methods

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Introduction

All pesticide labels contain very specific information regarding how they are to be stored, handled and used. It is illegal to use any herbicide in, on or over water unless it is registered for that purpose and has aquatic use directions on the label. States may have pesticide use regulations that are more strict than federal regulations; thus, several states require that aquatic pesticide applicators be certified and licensed before they may purchase, handle and apply pesticides and that permits are obtained before pesticides are applied. Potential users of pesticides should contact state agencies such as county cooperative extension offices, state game and fish agencies or state environmental authorities to ensure compliance with any additional state-specific use restrictions.

A few herbicides may be applied directly from the container; for example, the labels of some copper sulfate herbicides suggest placing the dry granules in a cloth bag and towing the filled bag behind a boat to ensure uniform application throughout the water column. However, the majority of aquatic herbicides must be diluted or mixed with water before application. The purpose of the diluent (water) is to ensure consistent coverage of the target weeds so the herbicide can be absorbed into the plants. Most herbicide labels state that applicators should "use sufficient diluent to obtain uniform coverage of the target weed." Some labels are more restrictive and specify the amount of diluent to be used during application of the herbicide. For example, a label may specify "apply in 50 to 150 gallons of water per acre for adequate coverage." The public often believes that the mixture being applied to weeds is concentrated herbicide, but this is rarely—if ever—the case because herbicides are mixed with large volumes of water. Applicators are required by law to have the label at the application site and it is critical that they read the label carefully before aquatic herbicides are diluted, mixed and applied to ensure that the herbicide is applied in a legal, appropriate and effective manner.

Foliar applications

Foliar herbicides are mixed with water and sprayed on the foliage of floating or emergent plants in a given area. The goal during foliar application of an aquatic herbicide is to obtain good coverage and ensure that the maximum amount of herbicide is taken up by the target weed. Most floating and emergent plants have a waxy layer (cuticle) on their leaves and stems that must be penetrated in order for the herbicide to be taken up by the plant. The labels of some aquatic herbicides suggest or require the addition of surfactants (Chapter 12) that dissolve the cuticle and facilitate uptake of the herbicide by the plant. For example, a label may state that "a surfactant may be applied at a rate of 0.25 to 0.5% (1 to 2 quarts per 100 gallons) with the tank mix to get best results." In this example, the addition of a surfactant is not required by the label so its use is optional; other labels require the use of surfactants.

Just as carpenters and electricians have specialized equipment for their work, aquatic applicators often have tank- and pump-equipped boats and trucks for the application of herbicide treatments.

A typical boat may hold a pump (calibrated to apply from 4 to 10 gallons per minute of a herbicide mix) and a 50- to 100-gallon mix tank. This equipment is calibrated to apply the correct amount of herbicide over the area to be treated. Selectivity, or the ability to control weeds growing among native plants, is usually accomplished by choosing the appropriate herbicide or by using a handgun to apply the herbicide mix only to the weeds and not to the desired native species. This is not always possible but is practiced as much as equipment and herbicide selection allow.

Most homeowners have small "pump-up" garden sprayers or backpack sprayers for lawn and garden use. Herbicide labels may include use directions for mixing the herbicide for small or localized spot treatments using small equipment. For example, if control of clumps of purple loosestrife along a shoreline is desired, the herbicide label may state "mix a 1 to 2% solution of herbicide in a backpack sprayer and spray weeds to wet." A gallon of water contains 128 fluid ounces, so the applicator would add 1.28 fluid ounces of herbicide to 127 fluid ounces of water to get a 1% solution. A 2% herbicide solution would be 2 x 1.28 fluid ounces, or 2.5 fluid ounces of herbicide per gallon of total tank mix. Be careful; some herbicides cannot be used in sprayers that will also be used for garden or ornamental plants, as some leftover herbicides can be quite toxic to other plants. Where is this information? On the label that is attached to every herbicide container!

The foliar application of herbicides to emergent and floating-leaved plants is generally well understood by homeowners because this is common practice on ornamental lawn and garden plants. The application of herbicides for submersed weed control, however, is often more complicated and thus more difficult to understand.

Submersed aquatic applications

The control of submersed aquatic weeds is much more difficult than control of emergent aquatic plants for the following reasons:

- Fewer herbicides are registered for submersed treatments
- The dilution effect of water depends on the depth of the water
- Wind, waves and currents dilute herbicides
- It takes more time to treat and cover submersed plants
- Submersed weeds are generally much more expensive to treat
- The growth stage and area covered by the plants are important
- Use of treated water for irrigation and drinking may be restricted

These general factors – and additional site-specific ones – determine which herbicides should be used to control submersed aquatic weeds. Water flow, dilution and water use are often the critical factors to consider when choosing a herbicide. Water flow and dilution may result in herbicide concentration/exposure times (CET) that are insufficient for herbicides to be effective (Chapter 11). There are also water restrictions on many herbicides for use in and adjacent to potable water intakes and for water used for irrigation. There are two general types of submersed aquatic weed applications, depending upon the CET requirements for the herbicides.

Contact herbicides

Contact herbicides are applied at relatively high concentrations, have very short half-lives in water and require a contact time of hours to a few days to kill plants. They include copper products, diquat, endothall and carfentrazone which may be applied along strips of shoreline and in relatively small areas where dilution is high, provided contact of the herbicide with the target weed is maintained for an amount of time sufficient to achieve control. The decision to use a contact herbicide is site-specific and the greatest chance of success occurs when herbicide applications are done on calm days to optimize contact times. Contact herbicides in general provide 3 to 6 months of weed control, depending upon the weed, geographical area of application (northern US vs. southern US) and length of growing season (Chapter 11).

Systemic or enzyme-inhibiting herbicides

Systemic enzyme-inhibiting herbicides are generally applied at concentrations lower than contact herbicides, must remain in contact with target weeds for relatively long times (up to 45 days or more) and are very slow to control submersed aquatic weeds. These herbicides are often applied as low-dose whole-lake treatments to control weeds throughout the lake. Systemic enzyme-inhibiting herbicides include fluridone, penoxsulam and imazamox. The former two herbicides are applied at rates of 5 to 20 ppb (parts per billion); concentrations can be maintained with additional treatments over several weeks to control hydrilla (Chapter 15.1), Eurasian watermilfoil (Chapter 15.2) and other submersed species. Imazamox is applied at 50 to 75 ppb and requires a contact time of several days. Penoxsulam and imazamox were registered in 2007 and 2008, respectively, and use patterns are still being developed (Chapter 11).

Systemic herbicides with short contact times

There are always exceptions to the rule, and 2,4–D and triclopyr are the exceptions in this case. Both are systemic herbicides but are absorbed in lethal doses by the target weeds in a relatively short time (1 to 4 days), depending upon the concentration applied. These two herbicides are effective for selective control of Eurasian watermilfoil and other dicot (non-grass) weeds. Concentrations of these herbicides for submersed weed control generally range from 1 to 2 ppm (parts per million). 2,4–D and triclopyr are applied at the highest labeled dose in areas where dilution is most likely to occur (such as small treatment areas and in strip treatments along shorelines) and on dense mature plants. Lower doses may be used in large treatment areas and in protected coves and bays with little water exchange.

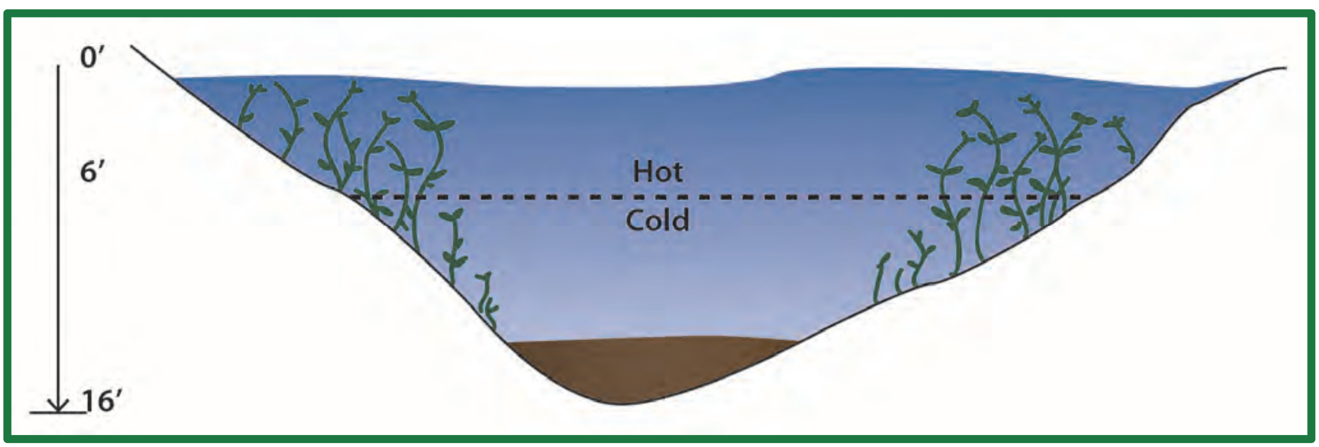
Application of formulations

Herbicide formulation refers to how a herbicide is sold (as a liquid, granular or other form) and this determines the type of equipment needed for application of the herbicide. Many aquatic herbicides are sold as both liquid and granular formulations because many are used for both foliar and submersed aquatic weeds. For example, you would not apply 2,4–D as a granular formulation for foliar applications to purple loosestrife (Chapter 15.12); you would use a liquid formulation. The formulations of common aquatic herbicides are listed in Chapter 11.

Liquid formulations can be applied to submersed aquatic weeds in several ways, with the type of application determined by the specific location, size and depth of the treatment area. Surface applications are typically done along shorelines and under or around boathouses and docks where water depths average 3 to 6 feet deep. Granular and deep-hose applications are often used in deeper water, particularly in water where submersed weeds are growing in water from 6 to 20 feet deep. The objective of these deep-water treatments is to ensure that the herbicide mixes in the water column and reaches the plant beds where they can be taken up by the target weeds.

Effect of thermoclines

Temperature-dependent thermoclines often develop in lakes and other non-flowing waters during summer, particularly in northern regions. A thermocline occurs when the upper and lower portions of the water separate into warm and cool layers. Swimmers are often familiar with this phenomenon; for example, water in the upper layer of a lake feels warm, but diving down to depths of 6, 8 or 12 feet can be shockingly cold. This thermal stratification is well-known to applicators of aquatic herbicides as well and can reduce the effectiveness of herbicide treatments because the warm upper and cool lower layers of the water do not mix. Herbicides applied to the surface of the water may control upper portions of weeds, but treatments do not penetrate into the deeper cool layers. As a result, root crowns, rhizomes and low-growing plants below the thermocline are not



controlled by the herbicide. The depth of the thermocline is influenced by water clarity and varies among lakes, but water temperature typically drops 2 °F for each 3′ change in depth. If aquatic weeds are growing above and below the thermocline, deep-water injection of liquid herbicides or application of granular herbicides may be used to control weeds in both thermal zones.

Foliar and submersed concentrations

The labels of glyphosate, 2,4–D, carfentrazone, triclopyr, diquat, endothall, copper, imazamox, imazapyr and penoxsulam products allow foliar applications for specific weed problems. Foliar-applied herbicides are usually mixed with 50 to 200 gallons of water per acre treated according to label directions and a surfactant is usually added to the tank mix to facilitate herbicide absorption or to ensure even coverage of the target plants. These herbicides are typically applied in "pounds per acre" with one pound of the herbicide's active ingredient in 100 gallons of water, resulting in a 0.1% concentration (1000 ppm). This relatively high concentration is needed to ensure that the plant absorbs enough herbicide to kill the weed on contact or through translocation to the site where the herbicide kills the plant.

Fortunately, application of herbicides for control of submersed aquatic weeds requires much lower concentrations of herbicides. This is because most submersed plants lack the waxy cuticles that slow herbicide uptake in many emergent plants and the leaves of many submersed plants are only a few cells thick. Tank mixes may still call for one pound of herbicide in 100 gallons of water, but in one acre-foot of water, the concentration of herbicide that contacts submersed plants is only 1/2.7 or 0.370 ppm (370 ppb) due to the dilution effect of the water being treated. Eurasian watermilfoil can be controlled with as little as 10 ppb of fluridone, but control of this weed with triclopyr or 2,4–D may require up to 2 ppm (2000 ppb). The ability of herbicides to control submersed weeds at such low concentrations contrasts sharply with the concentrations required to control larger, more tolerant floating and emergent weeds.

Although less herbicide is used per acre-foot of water for submersed weed control, submersed weeds often grow in water that is 8, 12 or 16 feet deep. Thus, submersed weed control often requires more herbicide per acre than foliar treatments due to increased water depth.

Selectivity

Weed control in an aquatic ecosystem is very different from weed control in an agricultural setting. For example, farmers want to control all the weeds in a cornfield without affecting the corn, whereas managers of natural and aquatic areas often wish to control a single weed species growing among 50 to 100 desirable native species. Research regarding selectivity of aquatic herbicides is ongoing and depends upon the following factors:

• Choice of herbicide: some herbicides control submersed weeds without affecting a number of other desirable nontarget plants, but the choice of herbicides that work in this manner is limited and complete selectivity is not always possible. As a result, herbicide selection is often dictated by the types of native species present in the proposed treatment area. In general, herbicides applied for submersed weed control have little effect on rooted emergent species due to the relatively low concentrations of herbicides used to control submersed weeds.
• Dose or amount of herbicide: not all plants are equally susceptible to herbicides. Application rates needed to control different weeds are usually listed on the herbicide label.

• Stage of plant growth: some herbicides used for submersed weed control can be applied in very early spring when weeds are actively growing and native plants are still dormant.
• Selective foliar application: handguns can be used to target and apply herbicides only to the weeds and minimize damage to nontarget species. However, this method is not feasible in most submersed treatments.

Although selective treatment of submersed weeds is more difficult than treatment of floating and emergent weeds, the reduction in growth and coverage of submersed weeds generally results in less weed competition and quick recovery of native species in the treated area. This occurs because most submersed weeds reproduce using vegetative means and many nontarget native plants reproduce by seeds. Elimination of dense weed canopies and the reduction of competition from invasive weeds often results in germination and growth of desirable species during the season of the herbicide treatment or soon thereafter.

Summary

Small-scale foliar application of herbicides to emergent and floating weeds is easily within the capabilities of most riparian homeowners, provided the correct herbicide is chosen and label directions are followed. The application of herbicides to aquatic weeds in large areas or for submersed weed control is more expensive, complicated and often requires specialized equipment to obtain the most cost-effective control. Selectivity results from a combination of factors, including herbicide choice, time of year and nontarget desirable species in the proposed treatment area. The size or area of the treatment site also affects the concentration-exposure time requirements for herbicides. In addition to label requirements, all these factors that affect submersed weed control clearly indicate that experienced state agencies responsible for permitting and managing aquatic resources be contacted prior to undertaking weed control projects.

For more information:

•How to build weighted trailing hoses. http://plants.ifas.ufl.edu/guide/building_weighted_trailing_hoses.html
•http://www.ecy.wa.gov/programs/wq/plants/management/aqua028.html
•http://aquat1.ifas.ufl.edu/guide/herbcons.html
•http://ohioline.osu.edu/a-fact/0015.html
•http://aquatplant.tamu.edu/index.htm
•University of Florida Center for Aquatic and Invasive Plants. http://plants.ifas.ufl.edu

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Page 194: Herbicide application; William Haller, University of Florida Center for Aquatic and Invasive Plants
Page 196 upper: Submersed herbicide application with trailing hoses; Thomas McNabb, Clean Lakes Inc.
Page 196 lower: Thermocline; Joshua Huey, University of Florida Center for Aquatic and Invasive Plants
Page 197: Herbicide application; William Haller, University of Florida Center for Aquatic and Invasive Plants

Appendix C: A Discussion to Address Your Concerns: Will Herbicides Hurt Me or My Lake?

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1. Our lake is pristine and we don't want to put dangerous chemicals in it. Why should we use herbicides now?

A pristine lake is balanced, stable... and very rare, especially when lakes are surrounded by homes or used for recreation. The lakes we live near and play in are often inundated by excess nutrients and foreign and invasive species. Most water bodies that require herbicide treatment have experienced explosive growth of invasive aquatic plants. While your lake may seem natural and pristine, there are sufficient nutrients in the water to allow exotic weeds – which don't belong in the lake – to dominate the system. Control of these weeds will enhance plant diversity and water quality (both of which are degraded by dense weed growth) and will help restore the overall health of the lake.

Your lake association or responsible public agency has evaluated all the options for aquatic plant management and has decided that the most effective means of controlling weeds at this point is to use herbicides. The herbicides that will be used are biodegradable and will not affect the pristine nature of the lake in the long term. When used by professionals according to label directions, herbicides are not "dangerous chemicals" but instead are curative products that have been extensively tested and can effectively control nuisance and invasive aquatic weeds.

2. How dangerous are these chemicals? How do we know they're safe?

Interestingly, aquatic herbicides are one of the smallest niches of specialty weed control products (Chapter 11), yet they are also among the most extensively tested. Because these products are added directly to water, the EPA requires extensive data to assess the safety of a herbicide before it can be registered for use in aquatic systems (Appendix A). Many years of testing and use have shown that registered aquatic weed control products can be used safely in all areas of the US. In addition, many years of safety and monitoring tests in the laboratory and in the field have been conducted to determine exactly how a given product should be used in a particular situation. It is also important to remember that the treatment level (or concentration in water) of a herbicide is typically much lower (100- to 1000-fold more dilute) than the concentration that might be harmful to you, your pets or nontarget organisms that live in the lake.

The data required by the EPA for registration of an aquatic herbicide are generated in studies that are conducted according to stringent protocols of conduct, design and evaluation. For example, a single study is conducted using a testing guideline that describes the number of organisms that must be tested, how they are housed and even the temperature and daylength under which the organisms must be maintained. The test is also governed by a series of "Standard Operating Procedures" that have additional parameters for testing and documentation. The guidelines for the test are further supported by a "Standard Evaluation Procedure", which outlines the criteria that must be met in order for the study to be defined as "acceptable." The EPA toxicologist produces a "data evaluation record" for the study and ultimately classifies the study as acceptable or unacceptable for incorporation into the risk assessment process. In a parallel requirement, the Standard Operating Procedures mentioned above must be conducted following formal "Good Laboratory Practice" requirements as outlined by the EPA. Good Laboratory Practice Standards are validated through both internal and external audits. Once a study has conformed to all of the requirements for study acceptance, data generated by the study are combined with data from all other acceptable studies of the herbicide and a risk assessment profile is developed.

The risk assessment process is complex and requires identifying which studies should be integrated into the hazard and exposure evaluation process. The 84 to 124 different studies required for registration of an aquatic herbicide take from 6 to 10 years to complete and are integrated in a robust scientific assessment that is evaluated by the EPA in a process that can take an additional one to three years before labels are approved.

3. Do these herbicides break down in the environment? I realize the herbicides themselves have been evaluated by regulatory agencies but what about their breakdown products?

Identification and evaluation of the components into which a herbicide breaks down is a critical and required part of the data that must be submitted as part of a product's registration process. Degradation and metabolism pathways must be studied and the molecules that are produced along those pathways must be identified. If any molecules are believed to be "of toxicological concern" (and there is a definition for that), then those molecules must be tested as well, both alone and in combination with the original or "parent" molecule.

Testing of breakdown products is not limited simply to toxicity; breakdown products must also be evaluated for their persistence in the environment. In addition, the mechanism (light, heat, microbial action) that produces them and acts to further break them down must also be understood. The final fate of the parent and breakdown products must be completely identified, reported and understood by chemists and toxicologists. Additionally, there are flagging criteria that are used to put "stop lights" on certain uses or environmental introductions of herbicides. These "stop lights" can be associated with direct toxicity, persistence, bioaccumulation or other important environmental and toxicological properties of the pesticide. If a product is flagged by one of these "stop lights" during testing, the company developing the product (especially one that will be used in water) may reconsider whether to proceed with the high cost of registration if there is a good chance the product will not successfully make it through the registration process.

4. If the chemical companies do the research and submit their data to the EPA, isn't this like the fox guarding the henhouse? Their data may be falsified!

With the current regulatory standards and rigor of EPA review, it is virtually impossible to falsify the data supporting a product. Companies submitting studies must certify that they are conducted in accordance with EPA regulations for good laboratory practices and usually hire independent quality assurance scientists to conduct audits as the studies are performed. In addition, the EPA has established a random laboratory and study audit program. This program has the authority to audit laboratories that conduct studies in support of pesticide registration and companies that sponsor them and can randomly select submitted studies for auditing. It must be possible during this audit process to confidently recreate the entire study from the "raw data" (laboratories are legally required to maintain all data for any submitted study on which registration relies). If a problem is found or the results cannot be reconstructed, not only is the study rejected for regulatory use, but the facility conducting it or the company sponsoring it is likely to undergo a more complete audit of all studies conducted during the same period, at the same facility or on the same product. Penalties for falsifying studies can be severe and include fines and/or imprisonment.

5. If herbicides make up only part of the chemicals that are applied, how do we know whether any other part of the product or its inert ingredients are dangerous?

First of all, let's understand a little bit about herbicide formulations. The chemical that controls the weed, in its pure form, is called the "active ingredient." The technical grade of the active ingredient is used in testing, and that technical grade must contain all those components that are found in the typical manufactured product that makes up the active ingredient. Technical grade chemicals are usually very pure (98%+), but may include additional compounds that are formed as the active ingredient is made. Components in the technical grade product, other than the pure active ingredient, are usually remnants of the manufacturing process, molecules that are impossible to separate from the parent compound, or other unintentionally added ingredients. All such impurities must be identified even if they are present in extremely low quantities. If any are of toxicological concern, they must be removed from the technical product or reduced to levels considered acceptable by the EPA.

Testing with the technical grade of the herbicide will identify toxic and environmental effects that might be caused by the active ingredient itself or any chemical components formed by the active ingredient. The technical grade form of herbicides are too concentrated and are rarely useable as herbicides without some modification to allow proper measurement (dilution by water, clay granules or other solvents or carriers), tank mixing (conditioners, such as emulsifiers, anti-foaming agents or wetting agents), and stability and distribution to the target site (by use of surfactants, drift control agents, dyes or other similar agents) (Chapter 12). The proper addition of these materials to the technical grade product produces an end use formulation, which is what is then purchased and used in weed control. This end use formulation must also be tested, but in a limited way unless the initial tests show that there is a measurable difference in toxicity between the technical product and its end use formulation. If there is a difference, the typical remedy is to change the components of the formulation so that they do not affect the toxicity or environmental characteristics of the end-use formulation.

Collectively, the formulation products discussed above are often referred to as "inert ingredients" because they do not contribute to the activity of the active ingredient. Formulations are considered trade secrets because their components may provide a competitive advantage and will be associated with a brand trademark. As such, the "secrecy" surrounding inert ingredients is one of competition, not toxicological properties. Additionally, not just any compound can be used in a formulation. The EPA requires that all inert ingredients in pesticide products be cleared prior to use and maintains a list of products from which the formulation chemist can choose. If the formulation chemist chooses a product that is not on the cleared list of inert ingredients, then supporting data must also be submitted for that "inert" ingredient. A separate and thorough review process will determine whether the inert ingredient can be added to the EPA's cleared list and safely used in the subject formulation. Incidentally, these inert ingredients are not "secret" from the EPA. Each technical and end use product must be supported by a complete "confidential statement of formula" so that the EPA can evaluate the acceptability of the full product and its additives. The confidential statement of formula is also used by the EPA when random or purposeful samples of the product are pulled from chemical plant distributors or applicators and analyzed for their compliance to the stated formula.

Inert ingredients in products to be used on food (and most aquatic uses are considered food uses due to the subsequent exposure to fish and shellfish, which in turn could be food items for people) or potable water must also have tolerances (allowable dietary levels of the product and any breakdown products of concern) set under the Federal Food, Drug and Cosmetic Act, which is administered by the Food and Drug Administration. Scrutiny of products that are used in, or may reach drinking water sources, is especially intense because the underlying assumption is that exposure could occur over a lifetime, from any and every drinking water source. In the case of aquatic herbicides, this assessment process greatly overstates exposure and thus results in a very conservative risk assessment.

6. When will it be safe for my kids to swim in the water again?

Each herbicide has a specific label statement regarding water use and swimming after weed treatment. Label statements are based on the results of various studies and the risk assessment process described above. Swimming restrictions listed on the label are most often related to the dissipation of the herbicide in water and added "safety factors" that build in at least a 100- to 1000-fold margin between what is observed in studies as a "no effect level" and the potential exposure level when a lake is treated. Therefore, the restriction interval (if any) is related to all studies conducted on the degradation and dissipation of the product and its dermal, oral and dietary toxicity, as well as any potential to irritate the skin or eyes or penetrate the skin. Herbicides that lack swimming restrictions may dissipate very quickly and/or the toxicity of the product at treatment levels is far below the "no effect level" in studies supporting product registration.

7. Will herbicide treatments kill the fish in our lake?

Aquatic herbicides are extensively tested for their effects on fish and other nontarget aquatic organisms. For the most part, these products are relatively non-toxic to fish because their mode of action (the way they affect the target weed) is based on photosynthesis or other plant processes that differ from animal biochemistry. A few types of aquatic herbicides (usually algicides) are toxic to fish at or near treatment levels, but application techniques that provide fish with the opportunity to escape from treated waters can reduce or prevent the loss of fish populations. This information is on the herbicide label; applicators are required to read and follow all label directions and precautions.

The applicator must consider the amount of plant cover and the manner in which it will be treated in his professional assessment of the needs of the lake. Decomposing vegetation can deplete oxygen levels in water, which can cause fish mortality if application precautions are not taken. Extreme infestations of weeds may require treatment of the lake in stages instead of using a single whole-lake treatment. Partial treatment will allow fish to escape to untreated, oxygenated waters as target plants in the treated area decompose.

8. The herbicide label says that the product is "toxic to fish and wildlife." Does this mean the herbicide treatment will kill our fish? If not, why do these chemicals kill plants without harming people or fish?

The statement referenced here historically has been required on a label when a pesticide intended for outdoor use contains an active ingredient with a fish LC50 (acute toxicity level) of less than 1 ppm [equal to one part (or molecule) herbicide per one million parts (or molecules) of water]. "LC50" is an abbreviation for "lethal concentration 50%" and represents the calculated concentration of the substance that is expected to kill 50% of the organisms studied. The standard label statement required in this case is, "This pesticide is toxic to [fish] [fish and aquatic invertebrates] [oysters/shrimp] or [fish, aquatic invertebrates, oysters and shrimp]." Likewise, if the product "triggers" a toxicity level preset for birds or mammals, a similar statement is required. When a pesticide intended for outdoor use contains an active ingredient which has a mammalian acute oral toxicity of less than 100 mg material/kg bodyweight, an avian acute oral toxicity of less than 100 mg/kg, or a subacute dietary toxicity of less than 500 ppm (500 parts of material per 1,000,000 parts diet, by weight), the label must state "This pesticide is toxic to [birds] [mammals] or [birds and mammals]." It is important to note that pesticides with lower LC50 values are more toxic than those with higher values. For example, a product with a toxicity of 100 mg/kg is more toxic than one with a toxicity of 250 mg/kg.

There are several circumstances that can make toxicity to organisms in the field less severe than suggested by the label statement when herbicides are used for weed treatment. Some of these are:
Effective control levels: most aquatic herbicides are applied at rates well below those that would cause fish or wildlife toxicity. This is either because the target weed is particularly sensitive to the herbicide or because the herbicide interrupts a biochemical pathway that animals do not possess.
Application techniques: your professional applicator or supervising state agency knows what precautions to take for products that have a treatment rate close to a wildlife effect level. These precautions can include partial lake treatments; optimal treatment timing at the lowest rate possible; the use of drift control agents; and other informed choices made by the professional applicator.
Dissipation rate: Some aquatic herbicides essentially break down immediately or are rapidly absorbed by plants and vegetative matter. Studies to determine fish toxicity are conducted in pure-water systems (without plants) over a period of several days. Such studies provide comparable standards for judging toxicity and regulating products, but they are not necessarily equal to fish exposure and product toxicity in a natural, living system when a herbicide is used according to label directions.
Sediment binding: Some aquatic herbicides ultimately bind to organic matter, algae and soil particles and partially end up in lake sediments, where they may be metabolized by microbes or made unavailable through the physical process of mineralization. A product that is bound in the soil this way rarely presents a toxicity concern.

9. Is it safe to eat fish from the lake after herbicides have been applied?

No aquatic herbicides currently registered by the EPA have fish consumption restrictions. There are no restrictions because herbicides have established “tolerances” that are set by the EPA and the FDA. Tolerances are boundaries for acceptable levels of pesticide residues in food and are established after review of submitted data and in accordance with the Federal Food, Drug and Cosmetic Act. If an aquatic herbicide has tolerances set for fish, then the label will instruct whether the fish can be consumed immediately after treatment or if there is a waiting period. Where there is no established tolerance (either because the registrant has not sought it or due to the properties of the product), the label will prohibit the consumption of fish from a treated lake until enough time has passed for no residues of the product to be found in fish tissues. Professional applicators are well aware of the restrictions necessary for fishing and fish consumption, as these restrictions are clearly specified on the herbicide label. Applicators are required to post signs or otherwise clearly inform lake users of any water use restrictions.

10. How long does it take for herbicides to break down? Do the chemicals become concentrated in the fish or the sediment of the lake?

There are some specialized terms that will help you understand the metabolic processes that are at the root of this question. They are adsorption, depuration, bioaccumulation and bioconcentration. Adsorption is the manner and rate at which an organism assimilates a chemical into its system, whereas depuration is the manner and rate at which the organism rids itself of a chemical. Bioaccumulation occurs when the rate of adsorption (taking up the chemical) exceeds the rate of depuration (ridding of the chemical) during the period of exposure. When exposure is stopped, depuration continues and the organism will gradually clear itself of the chemical. Some scientists debate whether there is a difference between bioaccumulation and bioconcentration. However, bioconcentration is slightly different than bioaccumulation because the levels of a chemical that bioconcentrates build up and become more concentrated over time. This occurs because depuration is non-existent or very slow, so the organism never clears the chemical from its system and may build up higher and higher concentrations upon every exposure to that chemical. Bioconcentration does not occur in any currently registered aquatic herbicide. A herbicide may have a short bioaccumulation period in edible organisms like fish and in such a circumstance would be labeled with restrictions to prevent consumption until the depuration process has cleared the chemical from the organism’s system.

Some aquatic herbicides may accumulate in sediments, but as discussed above, this is typically also associated with sediment binding that limits the biological availability of the product. The EPA takes into account potential accumulation of pesticides in fish and sediment prior to registering any product for use in water. In fact, pesticide accumulation in living systems or the environment is one of the “stop lights” discussed in Question 3 above. It is unlikely that any chemical that bioconcentrates would be registered for outdoor use in today’s regulatory environment. It is possible that a product that bioaccumulates might be registered, because in most instances this property can be managed by restricting application rates, treatment intervals and consumption of treated organisms. If risks to man or the environment are unacceptable or unmanageable, then the product simply will not be registered.

11. Are aquatic herbicides carcinogens? Will they give me cancer?

There are currently no registered aquatic chemicals that are classified as carcinogens. The treatment of water systems with herbicides is considered a widespread use with high potential for human and nontarget organism exposure. Consequently, products registered for use in water must present a very low risk profile, even when – in the case of aquatic herbicides – potential exposure to humans is neither pervasive nor long term. Any legitimate evidence of carcinogenicity would immediately put the registration and use of an aquatic herbicide in jeopardy.

This brings up an area that confuses many people – how to interpret different kinds of studies with respect to their validity for use in the "risk equation." A number of factors contribute to the validity of a study, such as the purity and reliability of the test system (contaminants not found in the product or nature, or the use of unusual species or strains of test animals that could create false results), the statistical power of the experiment itself (inadequate numbers of test organisms or improper statistical analysis of results could yield false conclusions), or the route of exposure (an exposure route impossible in nature, such as intravenous injection of high concentrations of chemical). For these reasons, some studies are not used in the risk assessment process, provided there is a body of reliable information that contradicts their findings. In the event a new finding is of concern, the EPA has the means to restrict use, cancel use or put other protective measures in place until additional data are generated or assessed.

12. Plants that have been treated with herbicides rot and sink to the bottom of the lake and cause a buildup of muck. We don't want muck buildup so we shouldn't use herbicides, right?

The best time to treat with herbicides is usually in the spring when plants are very actively growing but still small. This practice results in very insignificant organic matter additions to the lake. Furthermore, research has shown that when the growth of plants is restricted or controlled with herbicides or other means, much less organic matter is produced than if plants are left untreated. Plants that are not managed in some way grow until they reach their full annual biomass and then naturally die back each winter; as a result, all the material produced by a plant over the course of the year is added to the lake annually. By reducing plant growth, herbicide use can actually reduce organic matter production and accumulation. Another factor contributing to "muck" is sedimentation. Dense stands of weeds tend to trap particles suspended in the water column and increase sedimentation or "muck" buildup.

13. I've watched herbicide applications in other lakes and the applicators always wear "moon suits" and all sorts of protective gear even though the label says we can swim and fish immediately after application of the herbicide. This makes no sense – what gives?

Pesticide labels are developed to take into consideration both the exposure to workers (handlers and applicators) and the exposure to the environment. Workers repeatedly handle concentrated herbicides before they are diluted for application. Therefore, applicators are required to wear personal protective equipment to minimize their exposure to high doses of chemical if the chemical properties of the concentrated herbicide pose a risk to them. Herbicides are diluted literally millions of times when they are applied to water and they are usually applied once per season. As a result, the same precautions are simply not necessary for any lake water users who are not repeatedly exposed to high concentrations of herbicides. For comparison, a tablespoon of salt in a batch of yeast dough contributes to the flavor and perfection of the final loaves of bread – but a tablespoon of salt taken alone could be dangerous for you.

14. People used to say that DDT, chlordane and all those other pesticides were safe and now they're banned. Will this happen with more modern herbicides too?

DDT was first registered as a pesticide in the 1940s; chlordane was first registered in 1948. Both of these compounds were insecticides and are in no way related to any currently registered aquatic herbicides. There is absolutely no comparison to the testing standards and regulatory requirements in place today with the meager parameters that were in place in the first half of the last century. Needless to say, our understanding of science, toxicology and the environment has increased tremendously in the last 50 years.

The oldest registered aquatic herbicide appeared first in the late 1950s. Any products surviving since then have been subjected to additional reviews and many additional data requirements, culminating in updated and more rigorous risk assessments, including reregistration. It is a testimony to their safety that, as testing and registration requirements increase, older aquatic herbicides are still in use today. In fact, with the additional testing, many restrictions have actually been removed from older products. Products developed over the course of the last 30 years, during our cycle of increased understanding and advanced science, are designed to have a minimal impact on the environment and are simply not comparable to the "first generation" pesticides like DDT and chlordane. Today's products are developed with the knowledge of their toxicity and impact and would not be registered or commercially developed if they carried a high "risk burden."

15. I agree that we have to use herbicides to get our weed problem under control, but how can we as residents reduce the risks associated with the use of these chemicals?

First of all, by taking the time to read and understand this manual, you have already invested in reducing your own risks, because you now understand the importance of following label directions and the instructions provided to you by your professional applicator.

Second, plan carefully and completely for a herbicide application in the early stages of an aquatic weed infestation so that your lake can be treated at the optimum time of the year with the lowest effective treatment rates, which can reduce the need for multiple treatments. This action will likely provide more effective weed control, reduce costs and lower the total amount of chemical that may be required for adequate weed control.

Additionally, many states have regulatory agencies that conduct additional risk assessments to refine their understanding of product properties as specifically as possible for the conditions in their state. In some cases, specific permits or precautions are required on a treatment-by-treatment basis, thereby further ensuring that lake residents and users understand the restrictions, if any, on the use of the lake or its resources. For example, New York takes an additional precautionary step and adds another layer of protection by restricting swimming in any treated lake for 24 hours after any pesticide application to its waters – even though scientific data, the label and product properties do not call for this additional precaution.

The risk-reducing protections necessary for safe use of a registered product are already in place once the product is registered. All you have to do is follow the label, the instructions of the applicator and any additional local regulations.

16. What exactly is risk? I don't want any risk!

We cannot live in a risk-free environment. Living near a lake is in itself a "risk." Risk, as related to the science of risk assessment, is poorly understood by anyone other than risk-assessment scientists. Most people equate "risk" with "being exposed to a risk", but these are not the same thing. Risk assessors deal with the likelihood (or probability) of an event happening at all, while being at risk is the likelihood of being affected by an event that is known to happen. Thus, the risk assessor will come to a conclusion (for example) that a given dose of a chemical has a one in a million chance of causing cancer, while the statistician following causes of death will report that an individual has approximately a one in four chance of dying from cancer. Two very different endpoints.

When we put actual quantifiable risks in perspective, the risk of harm from an aquatic herbicide (or any pesticide, for that matter) is negligible. The National Safety Council (2005) reports the following:

- The leading causes of death in the US are heart disease, cancer, stroke, respiratory disease and unintentional accidents, in that order.
- Of unintentional accidents, the fourth ranked cause of death is drowning. The odds of drowning in natural water (as opposed to a swimming pool) are 1 in 2,378.

No risk estimate for the effects that might result from exposure to a pesticide even begins to approach this number.

In risk assessment, the end point sought is that the probability of a risk is so low that it is expected to not occur. In risk assessment, "risk" is defined as the relationship between hazard and the likelihood of exposure. When aquatic herbicides are used in a lake, most residents and lake users will have little or no exposure to the product used for weed treatment, based on the application methods, precautions taken and infrequency of treatment. Your risk of suffering from an event related to herbicide use and exposure is miniscule.

17. Does the EPA guarantee that these herbicides are safe?

The regulatory language of FIFRA (Appendix A) actually prohibits descriptive language that would imply any registered pesticide is "safe." In part, this is because "safe" is a relative term that could easily be misleading. No agent, natural or man-made, is completely "safe." Even water, which is essential for life, can be dangerous if too much is consumed because in excess it can disrupt the balance of electrolytes in a living system. Electrolyte imbalance can lead to shock and eventual death if not corrected.

As discussed above, EPA registration requirements and the risk assessment process supporting a pesticide registration are intense and thorough. The directions for use that are listed on the product label take into account risk management measures that are necessary to reduce the risk of exposure to the point where there is no reasonable expectation of environmental or human health effects.

Furthermore, there is now a revolving and formal Registration Review process, assuring that new scientific procedures and risk assessment methods are applied through a revolving process to all EPA registered products over the life of their registration.

18. Who else studies these chemicals besides the EPA?

Chemical use and its effects on the environment are closely scrutinized by many groups, including independent university scientists, state regulatory agencies, environmental groups and even the chemical companies themselves. Additionally, as the world economic and regulatory systems become more global, there is a closer coordination between countries in their requirements for and review of data on chemicals.

There are also protections written into FIFRA with respect to the discovery of previously unobserved effects. If a legitimate finding is made known to the company holding the registration for the chemical, that company must, within 15 days, report that finding and its significance to the EPA. If the EPA deems that the event is critical, it can immediately stop the sale or otherwise limit the use of the product. If the significance of the event is not major, but requires further understanding, the EPA may issue additional data requirements so that the initial finding can be studied and causes for it can be determined. Failure to follow these reporting requirements carries heavy penalties.

19. Big corporations are only interested in making money – they don't care whether their product is safe!

The development, registration and marketing of a pesticide take place in a highly visible segment of business in which relatively few companies compete. Add to that the extra burden of registering products for use in water systems and the general business risk couldn't get much higher. This is a mature industry with extremely high standards, a heavy regulatory obligation and a tremendous amount of exposure. Corporations employ scientists to conduct the research required for pesticide regulation, and these scientists eat the same food and use the same resources that we all enjoy. No company in such an environment would survive negligence, data falsification or poor business ethics. The mistakes of the early years that occurred in an emerging regulatory system and a budding scientific understanding of the environment that surrounds us are simply not inherent to the business today. They are of the past. Today's aquatic herbicide registrants are heavily invested in the safe and beneficial use of their products, environmental stewardship and sustainable practices. They have to be, or they wouldn't be here tomorrow. And being here tomorrow is how they survive, not simply by making money with no future in sight.

Appendix D: Developing a Lake Management Plan

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Introduction

Invasive aquatic plants are a major problem for the management of water resources in the United States. Nonnative invasive species cause most of the nuisance problems in larger waterways and often produce widespread dense beds that obstruct navigation, recreation, fishing and swimming and interfere with hydropower generation. In addition, dense nuisance plants increase the likelihood of flooding and aid in the spread of insect-borne diseases. Invasive plants also reduce both water quality and property values for shoreline owners.

Invasive species have a negative impact on the ecological properties of the water resource. They may degrade water quality and reduce species diversity while suppressing the growth of desirable native plants. Invasive species may alter the predator/prey relationship between game fish and their forage base, which results in higher populations of small game fish. Invasive species may also change ecosystem services of water resources by altering nutrient cycling patterns and sedimentation rates and by increasing internal loading of nutrients.

The most troublesome invasive plants that cause problems in the United States are listed in the following table. These species and recommendations for managing them are discussed in Chapter 15 of this manual. These exotic weeds are most likely to cause the greatest concerns, but many other native and nonnative species can cause problems as well, particularly in small areas or in ponds.

Submersed		
Common name	**Scientific name**	**Described in:**
Hydrilla	*Hydrilla verticillata*	Chapter 15.1
Eurasian watermilfoil	*Myriophyllum spicatum*	Chapter 15.2
Curlyleaf pondweed	*Potamogeton crispus*	Chapter 15.3
Egeria	*Egeria densa*	Chapter 15.4
Fanwort and cabomba	*Cabomba caroliniana*	Chapter 15.5

Emergent		
Common name	**Scientific name**	**Described in:**
Waterchestnut	*Trapa natans*	Chapter 15.6
Phragmites	*Phragmites australis*	Chapter 15.11
Purple loosestrife	*Lythrum salicaria*	Chapter 15.12
Flowering rush	*Butomus umbellatus*	Chapter 15.13

Floating		
Common name	**Scientific name**	**Described in:**
Waterhyacinth	*Eichhornia crassipes*	Chapter 15.7
Waterlettuce	*Pistia stratiotes*	Chapter 15.8
Giant and common salvinia	*Salvinia molesta*, *S. minima*	Chapter 15.9
Duckweed and watermeal	Multiple	Chapter 15.10

Development of a management plan

Water resource managers need to have an aquatic plant management plan for long-term management, even in bodies of water that have not yet been invaded by these exotic species. An effective aquatic plant management plan should establish protocols to prevent the introduction of nuisance plants, provide an early detection and rapid response program for the waterbody so new introductions can be managed quickly at minimal cost and aid in identifying problems at an early stage. The plan should also assist in identifying resources and stakeholders so that coalitions can be built to aid in the management of problem species. The planning process should include information that is already available and identify gaps in knowledge where more information is needed. An effective management plan will help water resource managers communicate the need for management of invasive species and provide a rationale or approach for management. A comprehensive aquatic plant management plan should have eight components: prevention, problem assessment, project management, monitoring, education, management goals, site-specific management and evaluation.

Prevention

The focus of a prevention program is education and quarantine combined with proactive management of new infestations (early detection and rapid response). Most invasive aquatic plants are introduced to a water body as a result of human activity and introductions most often occur when invasive plants are transported on boats, watercraft and boat trailers. Prevention activities can include signage at boat launches and marinas and other educational programs. Successful prevention programs utilize federal and state legislation, enforcement, educational programs in broadcast and print media and volunteer monitoring programs. An early detection and rapid response program should be employed in conjunction with prevention efforts to control new infestations at an early stage. Proactively controlling new infestations before they develop into large populations of exotic plants is both technically easier and less expensive, which results in major cost savings in the long run. The eradication of small populations is much more likely than eradication of large established populations. Early detection and rapid response is a critical component of an exotic species prevention program and is emphasized by federal agencies involved in invasive species management.

Problem assessment

Problem assessment should focus on identifying a problem in a given waterbody and collecting information about the problem. This information can then be used to formulate specific problem statements that define the cause of the problem. Problem assessment is the process of both acquiring objective information about the problem, such as maps and data on plant distribution, and identifying groups or stakeholders that should have input into formulating the problem statement. Problem assessments should also identify the causes of the problem and should increase the understanding of the water resource by reviewing information that is already available and highlighting areas where additional information is needed. A specific problem statement should be developed using the resources identified during problem assessment to aid in refining the concerns of users and the nature of the nuisance problem.

Project management

Project management is often a neglected aspect of managing invasive plants, particularly when volunteers manage the project. Successful projects are the result of good planning and management of assets, which include financial resources, partnerships, volunteers and other personnel. Detailed records of expenses must be maintained, particularly if the project is funded by government entities. In addition, a thorough evaluation of success of the program should include expenditures of both time and labor.

Monitoring

A monitoring program should include not only an assessment of the distribution of the target plant species, but also a program to monitor other biological communities (including desirable native plant communities) in the water body. Water quality parameters should be recorded on a regular basis to determine whether long-term changes have taken place in the water body and to assess whether management activities have had a positive or negative effect on other aspects of the water resource. Monitoring should also include baseline data collection (as outlined in the problem assessment section above), compliance monitoring involving a permit and assessments of management impacts to the environment at large. Successful monitoring programs often include a "citizen" monitoring component. For instance, citizen monitors have assessed water quality in many water bodies for several decades using techniques as simple as measuring water clarity using a Secchi disk (see page 3). The largest volunteer network in the US is The Secchi Dip-In (http://dipin.kent.edu/secchi.htm), though many states also have a statewide volunteer network (e.g., Florida, http://lakewatch.ifas.ufl.edu/; Maine, http://www.mainevolunteerlakemonitors.org; and others).

Education and outreach

Education and outreach should be initiated at the beginning of the program and should continue throughout the project. Education initially consists of familiarizing the project group with the problem and possible solutions, which helps to build a consensus regarding the solution. As the program progresses, education efforts should be extended to include the public (in addition to stakeholders in the lake association) and to inform them of the problem, possible solutions and what actions the program is taking to address the problem. It is important to provide as much information as possible to the public and to be forthright and open about management activities. A public web page devoted to the management program can be a very successful tool but the project group should utilize local media outlets, such as newspapers and radio, as well. Also, if your project is successful, share your success with others through homeowners associations or your local county cooperative extension service.

Plant information and methods

The development of a program to monitor invasive plants requires a list of invasive, nonnative, native, endangered and threatened plant species in the waterbody, maps marked with the locations of species of concern or species targeted for management, locations of nuisance growth and bathymetric maps. Quantitative plant data (sampling for plant distribution or abundance using a recognized sampling protocol) should be used for assessment, monitoring and evaluation as often as possible. Quantitative data is more desirable than qualitative data (subjective assessments such as "a big population" or "heavily infested") because:

- Quantitative data is objective and provides hard evidence regarding the distribution and abundance of plants, whereas subjective surveys are based on opinion rather than fact

• Quantitative data allows for rigorous statistical evaluation of plant trends in assessment, monitoring and evaluation
• Quantitative data and surveys may eliminate costly but ineffective techniques in a given management approach
• Quantitative data allows individuals other than the observer to evaluate the data and to develop their own conclusions based on assessment, monitoring and evaluation data

Plant quantification techniques vary in their purpose, scale and intensity (see table below). Cover techniques include both point and line intercept methods. These techniques yield the most information regarding species diversity and distribution and can reveal small changes in plant community composition. The best method for measuring plant abundance remains biomass measurement but this is time-intensive and usually reserved to evaluate the effectiveness of management activities. Hydroacoustic surveys measure submersed plant canopies while the plants are still underwater and are excellent for assessing the underwater distribution and abundance of submersed plants; however, this technique is unable to discriminate among species. Visual remote sensing techniques, whether from aircraft or satellite, have also been widely used to map topped-out submersed plants or floating and emergent plants.

Aquatic Plant Quantification Techniques	
Technique	**Information produced**
Cover techniques: point intercept	Species composition and distribution (whole-lake)
Cover techniques: line intercept	Species composition and distribution (study plot)
Abundance techniques: biomass	Species composition and abundance
Hydroacoustic techniques: SAVEWS	Distribution and abundance (no discrimination among species)
Remote sensing: satellite, aircraft	Distribution (plants near the surface only, no discrimination among species)

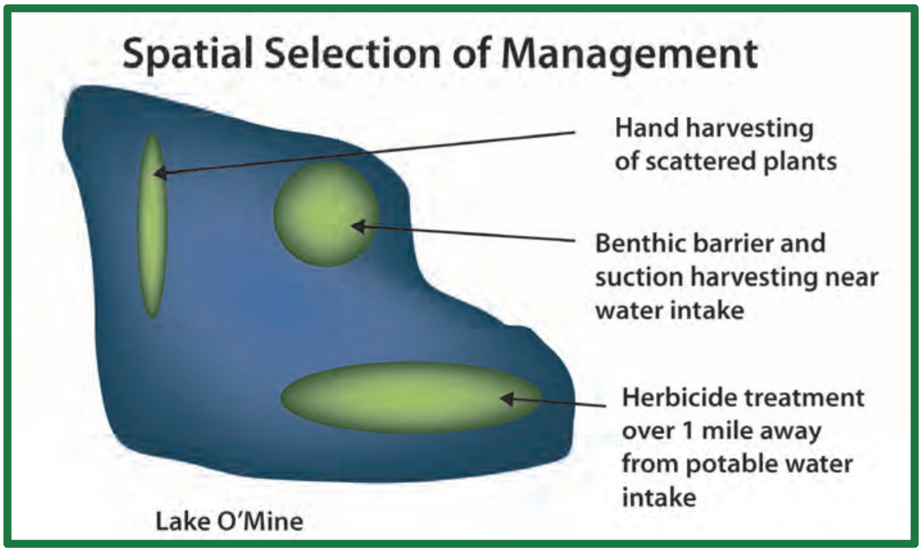
Management goals

Specific management goals that are reasonable and testable should be formulated as part of the management plan. This set of goals provides the milestones that can be used to determine whether the management program is successful. If specific management goals are not established, stakeholders may dispute whether management efforts have been successful since they may lack a clear understanding of the expectations of the management program. Goals should be as specific as possible, including indicating areas that have a higher management priority.

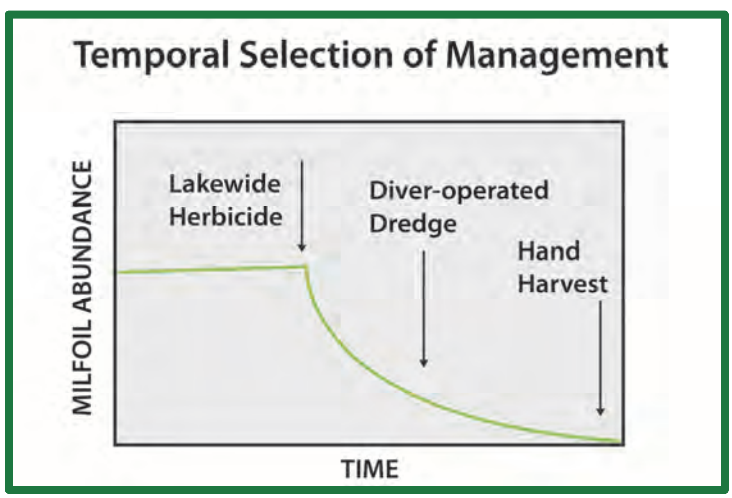
Providing stakeholders with a specific set of goals will allow them to evaluate quantitative data to determine whether management goals have been met. For instance, if vegetation obstructs recreational use of the waterbody, a goal of “unobstructed navigation” is vague and may result in unending management. If, however, the goal is to maintain navigation channels in navigable condition 90% of the time, then the success of the management program can be measured, tested and compared to the specific goal. Once plant management goals are developed, methods to achieve the goals should be implemented using techniques that are acceptable to stakeholders and regulatory agencies based on environmental, economic and efficiency standards. Management techniques will vary based on conditions within the water body and frequently change over time; this is referred to as site-specific management.

Site-specific management

Site-specific management utilizes management techniques that are selected based on their technical merits and are suited to the needs of a particular location at a particular point in time. Techniques should be selected based on the priority of the site, environmental and regulatory constraints of the site and the potential of the technique to control plants under the site's particular conditions.



Spatial selection criteria include the identity of the target weed species, the density of the weed, the size of the infested area, water flow characteristics, other uses of the area and potential conflicts between water use and restrictions associated with selected management techniques. For example, consider an area of nuisance growth that is close to a drinking or irrigation water intake. The primary use of the water (i.e., drinking or irrigation) may preclude the use of herbicides that cannot be applied to waters used for drinking or irrigation; therefore, the most appropriate control method for this area might be the use of a benthic barrier and suction harvesting. Consider another site that is more than a mile from the same intake. Weeds at this site could be controlled with herbicides without restrictions on other uses (provided the label specifies use of the herbicide in the area). Perhaps you have an area that is colonized mainly by scattered plants instead of dense stands. If the goal is to eradicate the plant from the water body and you have volunteers at your disposal, hand pulling may be the best method to prevent the formation of dense beds of the weeds.



Management techniques may change over time based on the success (or failure) of the management program. For example, consider Long Lake in Washington State, a small body of water that was dominated by Eurasian watermilfoil (Chapter 15.2) throughout more than 90% of the littoral zone. A whole-lake treatment of fluridone was applied to Long Lake, which reduced the biomass of the weeds by more than 90%. Small remaining beds in the second year were managed with diver-operated suction harvesting, benthic barriers or spot treatment with contact herbicides. By the third or fourth year, routine surveys found only sporadic Eurasian watermilfoil fragments, which were removed by hand harvesting. Similar treatment programs have been successful in other water bodies as well, which demonstrates that it is appropriate to alter management techniques as weed control requirements change over time. A wide variety of aquatic plant management techniques may be employed and include physical (Chapter 6), mechanical (Chapter 7), biological (Chapters 8, 9 and 10) and chemical (Chapter 11) control methods. Regardless of method, all techniques should be selected based on their technical merits, as limited by economic and environmental thresholds.

Evaluation

Evaluation of management techniques and programs is typically lacking, even in large-scale management programs. A quantitative assessment should be made to determine the effectiveness of weed management activities, identify environmental impacts (both positive and negative) of management activities, provide the economic cost per acre of management and address stakeholder satisfaction.

Summary

It is critically important to develop a management plan to effectively prevent and control invasive aquatic plants in water resources. Planning should be a continuous process that is ongoing and evolves based on past successes and failures. A comprehensive plan should educate the public about invasive species so they can identify and exclude weeds from uninfested areas. Aquatic plant management programs should also provide a concise assessment of the problem, outline methods and techniques that will be employed to control the weed and clearly define the goals of the program. Mechanisms for monitoring and evaluation should be developed as well and information gathered during these efforts should be used to implement site-specific management and to optimize management efforts. The planning process helps to prepare for the unexpected in weed management, but resource managers should expect the plan to change as stakeholders provide input and management activities commence.

For more information:

•Cover techniques: point intercept (species composition and distribution in the whole lake)
http://el.erdc.usace.army.mil/elpubs/pdf/apcmi-02.pdf
•Cover techniques: line intercept (species composition and distribution in a study plot)
http://el.erdc.usace.army.mil/elpubs/pdf/apcmi-02.pdf
•Abundance techniques: biomass (species composition and abundance)
http://www.hpc.msstate.edu/publications/docs/2007/01/3788JAPM_45_31_34_2007.pdf
•Hydroacoustic techniques: SAVEWS (distribution and abundance; no discrimination among species)
http://www.erdc.usace.army.mil/pls/erdcpub/docs/erdc/images/SAVEWS.pdf
•Remote sensing: satellite, aircraft (distribution of plants near the surface only; no discrimination among species) http://rsl.gis.umn.edu/Documents/FS7.pdf
•Rockwell HW Jr. 2003. Summary of a survey of the literature on the economic impact of aquatic weeds. Aquatic Ecosystem Restoration Foundation, Lansing, MI.
http://www.aquatics.org/pubs/economic_impact.pdf

Photo and illustration credits:

Page 213 upper: Nuisance growth near a water intake; John Madsen, Mississippi State University Geosystems Research Institute
Page 213 lower: Long Lake herbicide treatment; John Madsen, Mississippi State University Geosystems Research Institute

Appendix E: A Manager's Definition of Aquatic Plant Control

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Introduction

It would seem like a simple task to define "control", but this appendix illustrates how difficult and variable the term can be. Even scientists argue about the definition of control. For example, entomologists who release a potential biocontrol agent (Chapter 8) may define control as a 10% reduction in plant growth, but most lake managers and homeowners disagree. Do barley straw, enzymes and bacteria really control algae (Chapter 13)? Can native insect populations be augmented to provide weed control? Much depends on the definition of "control."

Defining aquatic plant control

During the past few decades demand for access to and use of US surface waters has increased. These uses include real estate, recreation, irrigation, hydropower, potable water, navigation and efforts to conserve environmental attributes such as fish and wildlife habitat. Aquatic plants are a natural and important component of many freshwater systems and resource managers consider a diverse assemblage and a moderate level of aquatic vegetation to be beneficial for numerous ecosystem functions. Nonetheless, an overabundance of aquatic plants, particularly invasive nonnative plants, can impair freshwater systems, requiring some level of aquatic plant management to conserve water body uses and functions. These aquatic plant management activities routinely take place on water bodies ranging in size from small private ponds to large public multi-purpose lakes and reservoirs.

With increasing demands and values associated with surface waters has come a greater need for aquatic plant control. Nonetheless, the term "control" can take on many meanings depending upon the type and amount of use of each water body, the species of plants present, the responsibilities of resource managers and the objectives of various stakeholder groups associated with the water body. A quick review of reference materials provides the reader with dozens of descriptions and synonyms for "control", and yet for various reasons none provide a meaningful definition for aquatic plant management. The Aquatic Plant Management Society (APMS) has requested that we address this deficiency by providing an aquatic plant manager's working definition of aquatic plant control.

While the terms aquatic plant control and aquatic plant management are often considered synonymous, many resource managers consider control efforts as being operational in nature and management as a process more aligned with program goals and objectives. The APMS defines aquatic plant control as techniques used alone or in combination that result in a timely, consistent and substantial reduction of a target plant population to levels that alleviate an existing or potential impairment to the uses or functions of the water body.

This definition best applies to management techniques that directly target a reduction in plant biomass. It is recognized that some management strategies seek to impact factors such as plant reproductive capacity (e.g., production of flowers, seeds, tubers, etc.) or nutrient availability; while these techniques are often recognized as a valuable component of an integrated management program, physical reduction of plant biomass may not result for many years. Moreover, in our definition, the use of the term "substantial" may seem ambiguous; however, we feel there is an inherent problem with using quantitative guidelines (e.g., a 70% reduction in biomass results in acceptable control) to define what is in most cases a series of qualitative field observations by the aquatic resource manager and stakeholders to determine the success of the management activity. Aquatic resource managers should always consider if the proposed management technique has a successful track record and know the limitations of the potential strategy. Claims that a product or technique can provide control should be supported by peer-reviewed literature, experiences from other resource managers with similar management objectives or current research and demonstration efforts.

No single definition of aquatic plant control can cover each specific contingency; therefore, good communication on the front end is key. The resource manager and stakeholders must first establish expectations for the amount and duration of plant control prior to the initiation of a control activity and then implement a management strategy to meet these expectations. This definition and the following discussion are intended to address factors that relate directly and indirectly to aquatic plant control. Numerous variables influence aquatic plant control operations and many of these parameters, including water body uses, environmental conditions and available management tools, are presented throughout this handbook, along with the influences they may have on the planning or outcomes of aquatic plant control operations. This information may be useful to managers responsible for conserving identified uses and functions of public waterways and who must explain to stakeholders the reasoning behind management plan selection and the ultimate results.

Linking management decisions to aquatic plant control expectations: factors that influence decisions and outcomes

Aquatic plants have been controlled in US surface freshwaters under organized programs for more than a century, so it is natural to ask why it is necessary to provide a definition of aquatic plant control at this point in time. In questioning a number of managers, researchers and other stakeholders, it became obvious that opinions on what constituted acceptable control of an aquatic plant population varied widely. While agricultural managers have been using terms such as "weed free periods" and "crop yield reductions" to define the economic benefits of weed control in cropping systems, aquatic plant managers have a different focus than their terrestrial counterparts. Agricultural weed managers usually attempt to control a broad spectrum of weeds in order to enhance one or more crop species in a fairly controlled environment with a specific function. Aquatic plant managers usually try to control one or two weeds (usually invasive exotic species) to conserve or enhance perhaps dozens of desirable plants as well as multiple uses of aquatic systems. In essence, an agricultural definition of "weed control" does not encompass the issues associated with aquatic plant management.

In developing a manager's definition of control, it was initially tempting to utilize the language of research to provide a quantitative definition. Both the amount and duration of plant control can be readily quantified within the framework of an experimental study or demonstration project. Nonetheless, many experimental studies result in destructive sampling of the target plants at a given point in time (e.g., 90% reduction 8 weeks after treatment) and they often don't allow us to determine if even better control or subsequent recovery would result at a later point in time. While this efficacy information can be very useful to managers regarding the expected performance of a management technique, the uses, functions and environmental conditions can vary widely among water bodies and within water bodies through time. This will influence not only the level of management that may be attempted, but also the outcomes of each control operation. While research projects utilize methods that allow for quantification of control, the vast majority of aquatic plant control operations are ultimately judged by fairly subjective visual observations and qualitative means (e.g., the target plants are near the bottom, difficult to find and the current level of control is rated as good). Therefore, plant control or lack thereof is largely based on whether or not the resource manager and stakeholder expectations have been met.

As noted above, there are numerous issues that either directly or indirectly influence aquatic plant control and management strategies. Before selecting control tools or developing management strategies, three key elements should be addressed that will ultimately influence the manager's decision making process.

Native vs. nonnative vs. invasive aquatic plant control

The National Invasive Species Council defines an invasive species as an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health. While there are major distinctions between invasive exotic and native species, the main objective of this paper is to clarify the term "control" and as such will not make significant distinctions between managing invasive exotic species and nuisance growth of native plants. Whether a plant is a native or exotic, it can cause problems for given water uses (e.g., water conveyance, access). Nevertheless, two key distinctions between nuisance native and invasive plants deserve further discussion. First, problems associated with nuisance native vegetation are typically site-specific, whereas invasive plants can impair uses and functions of waters across a broad spectrum of conditions and on a regional scale. The vast majority of large-scale aquatic plant control efforts in the US target invasive species. These plants have the potential to spread and dominate new ecosystems and they also have demonstrated the ability to become established in relatively stable aquatic systems. The philosophy behind invasive plant management programs often is to reduce the potential for spread within and among water bodies by reducing the plant biomass to the greatest extent practicable. The second distinction involves early detection and rapid response (EDRR) programs. These efforts are typically unique to invasive exotic species. A significant and costly multi-agency effort may be initiated to control a very small infestation; however, given the potential negative properties of many invasive exotic plant species, these front-end efforts are viewed as necessary and cost-effective.

Efficacy vs. control

It is tempting to define aquatic plant control in terms of an expected percent reduction in coverage or biomass of a target plant population. Some regulatory agencies (e.g., California EPA, Canada Pest Management Regulatory Agency) require that herbicide manufacturers prove the efficacy of their products prior to registration. In this regulatory scenario, a product must reduce a target pest population by greater than 70 or 80% to provide efficacy. Within the discipline of aquatic plant management, numerous techniques can provide both a rapid and significant reduction in a target plant population (>70%), but these results may only be sustained for a few weeks or months. Therefore, depending upon when the efficacy of a management technique is measured, one assessment may suggest that control was achieved, whereas a subsequent assessment conducted weeks, months or a season later may lead to the conclusion that the management effort failed to provide any level of control.

If resource managers and stakeholders have agreed to implement a strategy to provide an entire season of biomass reduction and the target plants recover within one or two months, then by our definition, control has not been achieved. In contrast, some methods may result in slow initial impact on a weed population, but may ultimately provide one or more seasons of control. To complicate matters, many stakeholders fail to grasp that an aquatic plant problem may require more than one treatment or strategy. It is incumbent upon resource managers to understand the strengths and weaknesses of the various management techniques and then convey this information to the stakeholders. If expectations are not defined properly, the stakeholder may lose confidence in the management program. When managers do not establish clear expectations, they are often questioned as to whether control was achieved. Attempting to assess aquatic plant control when clear expectations were not established on the front end is one of the biggest challenges in coming up with a meaningful definition or even assessment of control.

Environmental controls

Managers must be careful not to confuse slow-acting control methods with natural variations in plant populations. While it is often tempting to link a prior control effort with the large-scale decline of a target plant population, environmental events (e.g., droughts, floods, hurricanes, seasonal senescence, etc.) often are largely responsible for these declines. If sufficient data do not exist to support a cause and effect relationship between a control effort and plant biomass decline, managers should avoid making claims that cannot be supported by evidence. Some managers rely on environmental events (e.g., flooding events that scour submersed plants or move floating vegetation; prolonged periods of high, dark water that prevent light penetration for submersed plants) to provide control. While this can be effective, in order to be considered an aquatic plant management technique, there should be some level of predictability associated with the environmental event. From a management perspective there is a big difference in relying on routine seasonal flooding events to control a given plant population versus relying on 100-year floods or droughts to provide plant control.

Levels of aquatic plant control

At the most basic level, there are three possible aquatic plant control approaches:

1) no attempt to control
2) control efforts to eradicate a plant species
3) some level of intermediate control that is either incomplete or temporary

No attempt to control

Despite its connotation, the “no control” option is a valid management decision whose potential outcomes must be considered by managers and explained to stakeholders. Factors that influence a manager not taking active control measures may include:

- plant species – Is the plant invasive? Is it a native plant impairing water body uses or is it just unwanted by stakeholders?

- size of infestation – Is this a pioneer infestation consisting of a few plants? Is it an established, but stable, population? Is it an established population or starting to approach problematic thresholds?
- plant location – Is the infestation in an isolated location? Is the location conducive to spreading the pest plant by fragmentation, flow, etc.? Are there important nearby water bodies that are prone to becoming infested?
- plant biology – Is there a likelihood of a rapid population expansion? Would "no control" permit the plant to produce viable seed or vegetative propagules that could make later control efforts more difficult and expensive?
- exploitation – Is the plant species providing an ecological service (e.g., nutrient uptake, food source for waterfowl, habitat for fisheries, etc.)?
- managerial will – Managers may be under pressure to not control a plant because it provides benefits (perceived or real) to a user group. Stakeholders may oppose control because they are not familiar with proposed methods.
- managerial experience – Inexperienced resource managers are often uncomfortable with making aquatic plant management decisions (especially on a large scale). Until a manager understands the issues and situation, the "no control" option may be viewed as the safest and least controversial.

The consideration of these factors and others may justify a "no control" decision. There are consequences associated with all management decisions and "no control" is not exempt. As previously addressed, plant reductions related to environmental factors could be included within the realm of the "no control" option. While environmental events such as floods, droughts, freezes or severe algae blooms can be quite effective in controlling aquatic plants, these events are not typically predictable and they are not initiated by managers. Nonetheless, the fact that some managers tend to rely on seasonal or weather events to provide effective control suggests the term "no control" may be a misnomer in these situations.

Eradication

Much like defining control, eradication has proven to have numerous meanings to various managers, researchers and stakeholders. In a strict sense, eradication means the complete and permanent removal of all viable propagules of a plant population. This is confounded when a population is removed and then reintroduced at a later time. Some plants may be eradicated following single management efforts [e.g., removal of waterhyacinth (Chapter 15.7) plants prior to seed set], whereas others such as hydrilla (Chapter 15.1) may requires years of intense surveillance and management. Eradication efforts are typically employed when a region, state or watershed is threatened with a new introduction of an invasive species that has potential for significant economic or environmental impact. Based on efforts by various resource management agencies to date, aquatic plant eradication programs are characterized by:

- sustained and multi-year efforts to insure elimination of the plant population
- small-scale efforts to control relatively few plants
- control costs on a per acre basis can be quite high
- the overall impact of repeated control efforts on the infested water body is continually weighed against the regional threat posed by the invasive plant
- control efforts may eventually be reduced; however, vigilant monitoring remains a key to success

Temporary control

Outside the realm of eradication, all other control efforts are temporary. Temporary control is essentially an acknowledgement that 100% control is either not an economically viable management objective or is not possible. Temporary control is a continuum that can be represented by the short-term reduction of target plants following mechanical harvesting or spot treatments with contact herbicides to many years of control that may result from grass carp (Chapter 10) stocking for submersed plants or decades of suppression of alligatorweed by the alligatorweed flea beetle (Chapter 9). Thus, temporary control results when the aquatic plant manager has made the decision that eradication is not a viable endpoint and some level of target plant persistence is acceptable in the management strategy for a given water body.

Temporary control is achievable using a variety of methods. Managers should evaluate each proposed method and the integration of various methods in terms of meeting specific control objectives.

Maintenance control

Maintenance control is applied on a lake-wide or regional scale over time, usually to reduce and contain invasive species. Once established, invasive aquatic plants can be extremely difficult, if not impossible, to eradicate. However, managing invasive plants at some prescribed level that does not impair the uses and functions of the water body can reduce environmental and economic impacts. As the term implies, maintenance control indicates that a conscious decision has been made to actively control an aquatic plant problem with the understanding that a long-term commitment to management rather than eradication is the goal. Simply stated, maintenance control involves routine, recurring control efforts to suppress a problem aquatic plant population at an acceptable level.

Maintenance control encompasses a continuum of control objectives. On one extreme, the goal of maintenance control may be to reduce and sustain a plant population at the lowest feasible level that technology, finances and conditions will allow. This strategy has proven effective in managing established populations of highly invasive aquatic plants. By managing waterhyacinth at low levels through frequent small-scale control operations, there is a corresponding reduction in the overall management effort, especially herbicide use and management costs. There also are environmental gains, such as reductions in sedimentation and dissolved oxygen depressions. At the other end of the spectrum, maintenance control operations can be applied just prior to plant populations impairing the uses or functions of the water body. This strategy entails allowing plants to grow to the brink of problem levels and therefore may be best employed to control slow-growing or otherwise non-invasive plants.

Paradoxically, there is often more stakeholder support for crisis management (allowing plants to reach some problem or impairment level) than maintaining invasive species at low levels. This may be related to stakeholders being unaware of invasive plant growth potential. It also may be related to the public's perceptions of control methods – for example, not understanding that less herbicide may be needed to maintain plants at low levels rather than waiting for an obvious problem to develop.

Adaptive management

Since maintenance control represents a long-term commitment, it must also encompass a strategy known as adaptive management. Uses and functions of water bodies change through time, as do conditions within water bodies and among plant populations. Examples include target and nontarget plant growth stages, water temperature, depth, clarity and flow. All change several times during the year and can require different control strategies or different expectations for control outcomes. Therefore, integrated management plans for each aquatic plant control operation must account for and adapt to these changes.

Communicating control expectations to user groups

Many stakeholders view aquatic plant management endeavors as a one-time control effort with no further need for additional management. This does not reflect the reality of the discipline of aquatic plant management. The vast majority of management programs require a sustained effort over multiple years to keep unwanted vegetation under control. For example, while grass carp can provide long-term control of hydrilla, this result is due to their continuous presence and feeding on any plant regrowth. Carp can sustain control for many years, yet removal of the carp due to natural losses or on purpose will typically result in the recovery of the target plant. Likewise, a single treatment with the herbicide fluridone (Chapter 11) may remove a target invasive plant such as Eurasian watermilfoil (Chapter 15.2) within a system for one to several years. Upon discovery of new plants, many stakeholders are dismayed that the treatment did not eradicate the problem. In some cases these plants may have regrown from seed or they may have been introduced from a nearby lake or reservoir that was not managed. Aside from the use of an effective classical biological control organism (highly selective – Chapter 8) or high stocking rates of grass carp (non-selective – Chapter 10), user groups must be informed about the importance of maintaining continuity in an aquatic plant management program. Single small-scale efforts that don't address the problem at an adequate scale often lead to claims that "we tried that and it didn't work." A lake full of hydrilla or Eurasian watermilfoil may require whole-lake management efforts. The control may last one, two or more seasons, but experience suggests that these invasive plants will ultimately return.

One of the bigger challenges facing aquatic resource managers relates to the promotion of unproven and often costly technologies that are packaged as environmentally friendly approaches to aquatic plant management. As noted earlier, claims of a product or device providing "control" should be supported by published or ongoing research or by another reputable resource manager who has successfully applied that technique or strategy and met similar control objectives.

Appendix F: Miscellaneous Information

Lyn A. Gettys: University of Florida, Davie FL; lgettys@ufl.edu
William T. Haller: University of Florida, Gainesville FL; whaller@ufl.edu
David Petty: NDR Research; Plainfield IN; dpetty@ndrsite.com

Common names, trade names, formulations and registrants or suppliers of EPA-registered aquatic herbicides and algicides. Labels, MSDS and other product information is available on the websites of most registrants or suppliers. This is not a complete listing of all products that are registered for aquatic use and does not include products labeled only for use on ditchbanks. The mention of a trade or brand name does not constitute an endorsement of the product by the authors, editors or AERF.

Bispyribac-sodium		
Trade name	**Formulation**	**Registrant or supplier**
Tradewind	Water-soluble powder	Valent USA Corp.

Carfentrazone		
Trade name	**Formulation**	**Registrant or supplier**
Stingray	Liquid	SePRO Corp.

Diquat dibromide		
Trade name	**Formulation**	**Registrant or supplier**
Alligare Diquat	Liquid	Alligare LLC
Harvester	Liquid	Applied Biochemists
Littora	Liquid	SePRO Corp.
Nufarm Diquat SPC 2SL	Liquid	Nufarm Americas Inc.
Reward	Liquid	Syngenta
Weedtrine-D	Liquid	Applied Biochemists

Endothall		
Trade name	**Formulation**	**Registrant or supplier**
Hydrothol 191[1]	Liquid	United Phosphorus Inc.
Hydrothol Granular[1]	Granular	United Phosphorus Inc.
Teton[1]	Liquid	United Phosphorus Inc.
Aquathol K[2]	Liquid	United Phosphorus Inc.
Aquathol Super K[2]	Granular	United Phosphorus Inc.
Cascade[2]	Liquid	United Phosphorus Inc.

[1] Amine salt of endothall

[2] Potassium salt of endothall

Flumioxazin		
Trade name	**Formulation**	**Registrant or supplier**
Clipper	Water-dispersible granule	Valent USA Corp.

Fluridone		
Trade name	**Formulation**	**Registrant or supplier**
Alligare Fluridone	Liquid	Alligare LLC
Avast!	Liquid	SePRO Corp.
RESTOREs.m.a.r.t	Liquid	Applied Biochemists
Sonar AS	Liquid	SePRO Corp.
Sonar Genesis	Liquid	SePRO Corp.
Sonar H4C	Granular	SePRO Corp.
SonarOne	Granular	SePRO Corp.
Sonar PR	Granular	SePRO Corp.
Sonar Q	Granular	SePRO Corp.
Sonar RTU	Liquid	SePRO Corp.

Glyphosate		
Trade name	**Formulation**	**Registrant or supplier**
Alligare Glyphosate 5.4	Liquid	Alligare LLC
Aquaneat	Liquid	Nufarm Americas Inc.
AquaPRO	Liquid	SePRO Corp.
Shore-Klear	Liquid	Applied Biochemists
ShoreKlear-Plus	Liquid	Applied Biochemists

Imazamox		
Trade name	**Formulation**	**Registrant or supplier**
Clearcast	Liquid	SePRO Corp.
Clearcast 2.7G	Granular	SePRO Corp.

Imazapyr		
Trade name	**Formulation**	**Registrant or supplier**
Alligare Ecomazapyr	Liquid	Alligare LLC
Habitat	Liquid	SePRO Corp.
Nufarm Polaris AC Complete	Liquid	Nufarm Americas Inc.
Nufarm Polaris Herbicide	Liquid	Nufarm Americas Inc.

Penoxsulam		
Trade name	**Formulation**	**Registrant or supplier**
Galleon SC	Liquid	SePRO Corp.

Topramezone		
Trade name	**Formulation**	**Registrant or supplier**
Oasis	Liquid	SePRO Corp.

Triclopyr		
Trade name	**Formulation**	**Registrant or supplier**
Navitrol[1]	Liquid	Applied Biochemists
Navitrol DPF[1]	Granular	Applied Biochemists
Alligare Triclopyr 3SL[2]	Liquid	Alligare LLC
Garlon 3A[2]	Liquid	Dow AgroSciences
Renovate 3[2]	Liquid	SePRO Corp.
Renovate OTF[2]	Granular	SePRO Corp.
Renovate LZR[2]	Granular	SePRO Corp.
Tahoe 3A[2]	Liquid	Nufarm Americas Inc.

[1] Triclopyr acid

[2] Triclopyr amine

Triclopyr + 2,4-D amine		
Trade name	**Formulation**	**Registrant or supplier**
Aquasweep	Liquid	Nufarm Americas Inc.
Renovate LZR MAX	Granular	SePRO Corp.
Renovate Max G	Granular	SePRO Corp.

2,4-D acid		
Trade name	**Formulation**	**Registrant or supplier**
Hardball[1]	Liquid	Helena Chemical Co.
Sinkerball[1]	Liquid	Helena Chemical Co.
Alligare 2,4-D Amine[2]	Liquid	Alligare LLC
Clean Amine[2]	Liquid	Loveland/CPS
Sculpin[2]	Granular	SePRO Corp.
Solution Water Soluble[2]	Granular	Nufarm Americas Inc.
Weedar 64[2]	Liquid	Nufarm Americas Inc.
Weedestroy AM 40[2]	Liquid	Nufarm Americas Inc.
Navigate[3]	Granular	Applied Biochemists

[1] 2,4-D acid

[2] 2,4-D amine

[3] 2,4-D butoxy-ethyl ester

Peroxides		
Trade name	**Formulation**	**Registrant or supplier**
GreenClean	Liquid	BioSafe Systems
GreenClean PRO	Granular	BioSafe Systems
PAK 27: *Hydrogen peroxide*	Granular	SePRO Corp.
Phycomycin SCP: *Sodium carbonate peroxyhydrate*	Granular	Applied Biochemists

Dyes		
Trade name	**Formulation**	**Registrant or supplier**
Aquashade	Liquid	Applied Biochemists
SePRO BLUE	Liquid	SePRO Corp.
SePRO BLUE WSP	Water-soluble pack	SePRO Corp.
SePRO Natural Reflections	Liquid	SePRO Corp.

Copper products		
Trade name	**Formulation**	**Registrant or supplier**
Captain[1]	Liquid	SePRO Corp.
Captain XTR[1]	Liquid	SePRO Corp.
Alligare 8% Copper[2]	Liquid	Alligare LLC
K-tea[2]	Liquid	SePRO Corp.
Symmetry NXG[2]	Liquid	United Phosphorus Inc.
Nautique[3]	Liquid	SePRO Corp.
Cutrine-Plus[4]	Liquid	Applied Biochemists
Cutrine-Plus Granular[4]	Granular	Applied Biochemists
Current[5]	Liquid	United Phosphorus Inc.
Harpoon[5]	Liquid	Applied Biochemists
Harpoon Granular[5]	Granular	Applied Biochemists
Komeen[5]	Liquid	SePRO Corp.
Komeen Crystal[5]	Granular	SePRO Corp.
AB Brand Copper Sulfate Crystals[6]	Granular	Applied Biochemists
Formula F-30[6]	Liquid	Diversified Waterscapes
SeClear[7]	Liquid	SePRO Corp.
Clearigate	Liquid	Applied Biochemists
Cutrine-Ultra	Liquid	Applied Biochemists

[1] Copper chelate: ethanolamine
[2] Copper chelate: triethanolamine
[3] Copper chelate: triethanolamine + ethylenediamine
[4] Copper ethanolamine complex, mixed
[5] Copper ethylene diamine complex
[6] Copper sulfate
[7] Copper sulfate pentahydrate and water quality enhancer
[8] Emulsified copper ethanolamine complex, mixed

For more information:

Alligare, LLC	www.alligare.com
Applied Biochemists (A Lonza Business)	www.appliedbiochemists.com
Diversified Waterscapes	www.dwiwater.com
Dow AgroSciences	www.dowagro.com
Helena Chemical Co.	www.helenachemical.com
Loveland/CPS	www.lovelandproducts.com
Nufarm Americas Inc	www.nufarm.com/USIVM/IVM
SePRO Corporation	www.sepro.com; www.stewardsofwater.com
Syngenta	www.syngenta.com
United Phosphorus, Inc.	www.upi-usa.com
Valent USA Corporation	www.valentpro.com

Common Conversion Factors (David Petty, NDR Research)

To change	To	Multiply by
acres	hectares	0.4047
acres	square feet	43,560
centimeters	inches	0.3937
centimeters	feet	0.03281
cubic feet	cubic meters	0.0283
cups	ounces (liquid)	8
cubic meters	cubic feet	35.3145
cubic meters	cubic yards	1.3079
feet/second	miles/hour	0.6818
gallons (U.S.)	liters	3.7853
grams	ounces (avdp)	0.0353
grams	pounds	0.002205
hectares	acres	2.471
inches	centimeters	2.54
kilograms	pounds (avdp)	2.2046
kilometers	miles	0.6214
liters	gallons (U.S.)	0.2642
liters	pints (liquid)	2.1134
liters	quarts (liquid)	1.0567
meters	feet	3.2808
meters	yards	1.0936
miles	kilometers	1.6093
miles	feet	5280
miles/hour	feet/minute	88
ounces (avdp)	grams	28.3495
ounces (avdp)	pounds	0.0625
ounces (liquid)	pints (liquid)	0.0625
ounces (liquid)	quarts (liquid)	0.03125
pints (liquid)	liters	0.4732
pints (liquid)	ounces (liquid)	16
pounds (avdp)	kilograms	0.4536
pounds	ounces	16
quarts (liquid)	liters	0.9463
quarts (liquid)	ounces (liquid)	32
square feet	square meters	0.0929
square kilometers	square miles	0.3861
square meters	square feet	10.7639
yards	meters	0.9144
1 ppm	= 1 mg/L or 1 mg/kg	
1 ppb	= 1 µg/L or 1 µg/kg	

Common Water Quality Parameters (David Petty, NDR Research)

Alkalinity: The water's ability to neutralize acids, measured in milligrams per liter of total alkalinity as equivalent calcium carbonate (mg/L $CaCO_3$). Alkalinity helps regulate pH and metal content in water. Levels of 20-200 mg/L are common in fresh water systems.

Conductivity: The measure of the capacity of water to conduct an electric current, measured in either microSiemens per centimeter of water at 25 degrees centigrade (µS/cm @ 25 °C) or micromhos per centimeter (µmhos/cm). Conductivity is an indirect measure of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium and iron.

Dissolved oxygen (DO): The amount of oxygen measured in water in milligrams per liter (mg/L). In general, rapidly moving water contains more dissolved oxygen than slow or stagnant water and colder water contains more dissolved oxygen than warmer water. Low DO levels can lead to fish kills. Optimal DO for many species is between 7 and 9 mg/L.

Hardness: Water hardness is generally the measure of the cations of magnesium and calcium in the water, usually expressed as mg/L. Waters with a total hardness in the range of 0 to 60 mg/L are termed soft; from 60 to 120 mg/L moderately hard; from 120 to 180 mg/L hard; and above 180 mg/L very hard.

pH: Scale of values from 0 to 14 which indicate the acidity of a waterbody. Water is acidic if pH is below 7, with increasing acidity with lower values. Water is basic when above 7, and more basic with increasing values. A value of 7 is considered neutral pH. Aquatic organisms differ in the pH range they can tolerate and flourish in.

Turbidity: A measure of the amount of particulate matter that is suspended in water, and is measured in Nephelometric Turbidity Units (NTU). Water that has high turbidity appears cloudy or opaque. High turbidity can cause increased water temperatures because suspended particles absorb more heat and can also reduce the amount of light penetrating the water.

Glossary of terms

Note: words in this glossary are defined in the context in which they are used in this manual

A

Abscission: a process in which part of a plant naturally detaches from the rest of the plant

Absorb: to soak up a substance

Acidic: having a pH of less than 7; compare to alkaline

Acre: an area containing 43,560 square feet

Acre-foot: the amount of water one foot deep in an area that covers one acre; equal to 325,851 gallons of water with a weight of approximately 2.7 million pounds; used to calculate the amount of herbicide to be applied to a body of water

Active ingredient: the specific chemical that has herbicidal activity and is responsible for killing or controlling a plant

Acute: severe or sharp, as in the shape of a leaf; or meaning rapid or quick when referring to toxicity

Adsorb: to bind to the outside or surface, such as herbicides binding to soil particles

Adsorption: the adhesion or accumulation of a substance onto another, such as herbicides binding to soil particles

Adventive: a nonnative organism that colonized an area long ago, developed a reproducing population and has become naturalized

Aeration: the introduction of oxygen to water, often accomplished with an aerator

Aerobic: containing oxygen; compare to anaerobic

Alkaline: having a pH of greater than 7; also called basic; compare to acidic

Allocation: distribution of a substance to different areas within an organism

Amphibian: an air-breathing organism that can live in terrestrial and aquatic environments

Amphipod: a small crustacean often eaten by juvenile fish

Anaerobic: lacking oxygen, as in some highly organic lake sediments; compare to aerobic

Annual: a plant that completes its entire life cycle in one year or season; compare to perennial

Anthropogenic: occurring as a result of human activity

Apical bud, apical meristem: a growing point in the uppermost portion of many plants

Arthropod: an invertebrate organism with a segmented body; examples include insects and crustaceans

Augmentation: a process where additional organisms are added to supplement existing populations; used in biocontrol

Auxin: a plant hormone that regulates growth

Axil: the area where the leaf stalk or petiole attaches to the stem

Axillary bud, lateral bud: a meristem or bud in the leaf axil or along the sides of stems; compare to apical bud

B

Ballast: weight, typically in the form of water, placed into the hull of a heavily loaded cargo ship to increase stability; usually removed or discharged when cargo is removed

Basic: see alkaline

Bathymetry: the measurement of water depths within a body of water

Benthic: relating to the bottom of a water body and the organisms that inhabit the sediments

Bioaccumulation: a process where a substance builds up in an organism after the organism consumes other organisms contaminated with the substance

Bioconcentration: the buildup of a substance in an organism at levels greater than the surrounding environment

Biocontrol: the use of an organism such as an insect or fish to control an invasive organism such as an aquatic weed

Biodiversity: a measure of the number of different species in an environment

Biomass: the amount of vegetative material (leaves, stems, etc.) produced by a plant

Biotype: an organism that differs (in appearance or another characteristic) from other organisms of the same species; sometimes referred to as a variety or subspecies

Brackish: a mixture of fresh and saline water

Bulblet: a bulb-like vegetative structure produced by some plants that is capable of forming a new plant

Bycatch: the unintentional trapping of organisms during mechanical harvesting of aquatic weeds

C

Calcified: the accumulation of calcium deposits on the leaves of a plant

Chelate: an organic compound which binds with ions such as copper

Chlorophyll: the green pigment in plants and other photosynthetic organisms that use light to produce energy

Chloroplasts: plant structures where sunlight is converted to energy

Clarity: the relative clearness of water; usually measured with a Secchi disk; compare to turbidity

Clones: organisms that are genetically identical to one another

Coevolution, coevolved: a process where different organisms in the same environment evolve or change in concert; for example, insects and plants that have evolved together over time to provide services to one another

Crown: the region of a plant where the stems and the root join together

Crustacean: an aquatic arthropod with a segmented body and hard exoskeleton; examples include lobsters, shrimp and crabs

Cuticle: a protective waxy layer that is present on the leaves of terrestrial plants but absent on the leaves of most submersed aquatic plants

Cyanobacteria: photosynthetic bacteria; also call blue-green algae

D

Deactivation: a process where a substance is rendered inactive due to a process within a plant or binding with the sediment

Defoliation: loss or removal of a plant’s leaves

Degradation: breakdown of complex organic compounds into simpler substances that are then further degraded or broken down

Depuration: cleansing or purification

Desiccate: to dry out by removing most or all water from an organism

Destratification: loss of the layering that occurs in bodies of water (usually during the summer) and results in water mixing across depths within a water body; see thermocline

Detritivores: organisms that eat detritus or other dead organic matter

Detritus: decomposed organic material (primarily dead aquatic plants) that settles on and in the sediment

Dewatering: the process of removing the water from an aquatic system; see drawdown

Dicotyledon (dicot): a plant characterized by having two seed leaves at germination and leaf veins that are arranged like a net; most broad-leaved plants are dicots; compare to monocotyledon

Diluent: a substance (usually water) used to reduce the concentration of a herbicide and to facilitate uniform application

Dioecious: a condition where individual plants bear only staminate (male) or pistillate (female) flowers; compare to monoecious

Diploid: an organism with two sets of chromosomes; usually fully fertile and able to reproduce by sexual means

Dissipation: the slow reduction in concentration and eventual loss of a substance through degradation, dilution or both processes

Dormant: a condition where plants cease growth in order to survive adverse conditions and resume growth when conditions improve

Drawdown: partial or complete removal of the water in an aquatic system for a period ranging from several months to several years to cause desiccation and death of aquatic weeds

Dredge: removal of part of the sediment in a water body to improve navigation and/or control aquatic weeds; also used to describe the equipment used in this process

E

Ecosystem: the flora, fauna and environmental conditions within a given area

Efficacy: effectiveness

Embayment: a bay-shaped indentation in the shoreline that is larger than a cove but smaller than a gulf

Emergent: a plant that is rooted in the sediment with most parts of the plant maintained above the waterline; examples include most shoreline plants such as cattail, purple loosestrife and pickerelweed

Emulsifier: a substance that is used to keep particles in solution in a fluid; often added to concentrated herbicides so they can be mixed with water

Endemic: considered native or naturally occurring in an area

End-use product: the final product purchased by applicators; usually manufactured with technical grade active ingredients and diluted with inert ingredients such as water and emulsifiers to make the product easy to dilute and apply

Entomology: the study of insects

Enzyme: a chemical that degrades or breaks down a substance or allows a chemical reaction to occur

Equilibrium: a balanced system with little change in the elements that comprise the system

Eradication: complete elimination of an organism from a system; see extirpated

Estuary: the wide part of a river where it nears the ocean

Eutrophic: rich in minerals and organic nutrients; eutrophic conditions encourage algae growth and reduce levels of dissolved oxygen

Eutrophication: the accumulation of excessive minerals and organic nutrients

Evergreen: a plant that maintains its leaves and sometimes continues to grow throughout the year

Exotic: not native to a region or system

Extirpated: see eradication

F

Fauna: collectively, the animals (including insects) present in a system

Floating–leaved: a plant that is rooted in the sediment and has leaves that float on the surface of the water; examples include waterlily and waterchestnut

Flora: collectively, the plants present in a system

Formulation: the form in which a herbicide is sold (liquid, granular or other form)

Fragmentation: a process whereby part of a plant is removed from the rest of the plant due to natural (see abscission) or mechanical means

Free-floating: a plant with roots that typically occupy the upper portion of the water column; examples include waterhyacinth and salvinia

G

Generalist: an organism that does not require a specific food source for growth, survival and reproduction

Genotype: the genetic composition of an organism

Genus: a classification that describes a group of closely related organisms; each genus is further divided into species, whose members are very closely related and can breed with one another

Geotextile: a specialized fabric-like material used to stabilize shorelines or to smother submersed aquatic weeds

GLP: an acronym for good laboratory practices, a set of protocols that must be followed when testing herbicides

H

Half-life: the period of time required for the concentration of a chemical to be reduced by half, usually by microbes, light or chemical reactions

Hardness: a measure of the amount of calcium and carbonates in water

Herbaceous: a “fleshy” plant with no little or no woody material

Heterogeneity: a measure of the genetic diversity in an organism; also used to describe diverse plant communities

Heterotypic: of a different form or type

Hydrology: the study of the properties, distribution and effects of water on the earth’s surface, soil and atmosphere

Hydrolysis: the splitting of a compound into two smaller parts as a result of contact with water

Hydropower: energy derived from the force of moving water

Hypereutrophic: extremely high in nutrients; characterized by excessive algae growth that causes water to be very cloudy with poor transparency

Hypolimnetic: pertaining to the hypolimnion, the cold deeper area of a stratified lake

I

Inactivation: a process where a substance is rendered inactive due to a process within a plant or binding with the sediment

Indigenous: native to a region or system

Inert: a substance that lacks herbicidal properties

Inflorescence: the structure and arrangement of a plant’s flowers

Insectivorous: insect-eating

Inundated: flooded or under water

Invasive: a species that steals resources from desirable species and reduces diversity by being more competitive than other organisms in the system; most invasive species are nonnative, fast-growing and lack natural enemies

Invertebrate: an animal that lacks a backbone

L

LC50: abbreviation for lethal concentration 50%; the external or applied concentration of a substance required to cause death in 50% of the organisms tested; similar to LD50 (lethal dose 50%)

Larvae: early stage of insect development; examples include maggots and grubs

Lateral: a bud or branch produced from a leaf axil or other non-terminal bud on the plant

Limnology: the study of freshwater systems, including lakes, rivers and ponds

Littoral: the zone near the shoreline where water is typically shallow; usually inhabited by aquatic plants

M

Macrophyte: a plant that can be easily seen without magnification

Macroscopic: an organism that can be easily seen without magnification

Meristem: the part of a plant from which new growth originates; also called a bud

Mesotrophic: having moderate amounts of nutrients and phytoplankton

Metabolite: the product resulting from chemical breakdown or degradation of a more complex organic molecule

Microbe: a tiny organism such as a bacterium or fungus; also called microorganism

Microcrustaceans: very small zooplankton or crustaceans that feed on phytoplankton and are not easily viewed without a microscope or magnifying lens

Microfauna: animals that are not easily viewed without a microscope or magnifying lens

Micronutrient: an element that organisms require in small quantities for healthy growth

Midrib: the central vein of a leaf

Mineralization: the conversion of an element from an organic form to an inorganic form as a result of microbial decomposition

Molting: the shedding of an insect's outer layer to allow expansion and growth

Monocotyledon (monocot): a plant characterized by having a single seed leaf at germination and leaf veins that are arranged in a parallel manner; grasses are monocots; compare to dicotyledon

Monoculture: a group of plants consisting solely of members of a single species

Monoecious: a condition where individual plants bear both staminate (male) and pistillate (female) flowers; compare with dioecious

Monotypic: composed of organisms of the same type or species

Morphology: the appearance of an organism

N

Native range: the geographic region from which an organism originates

Naturalized: a nonnative organism that reproduces and maintains a population in a new area; see adventive

Niche: a specific range of environmental conditions or a habitat in which a species can thrive

Nonindigenous: a nonnative organism

Nutlet: a small, hard, reproductive structure

O

Obligate: requiring a certain environment or food source to survive, grow and reproduce

Off-patent: a chemical that is no longer protected by a patent and can be produced by other companies in addition to the company that developed the product; often available in generic form

Oligotrophic: very low in minerals and organic nutrients

Omnivorous: consuming almost any type of plant or animal matter

Ornithology: the study of birds

Outcompete: make better or more efficient use of available resources than other organisms; deplete resources needed for growth of other organisms

Overwinter: to survive throughout the winter, often in a dormant state or as a propagule

Oxbow: a sharp, U-shaped bend in a river that is no longer attached to the river

Oxygen: present in water at concentrations ranging from 0 to 15 ppm; few fish can survive extended periods when oxygen content is below 2 ppm

Oxygenation: to increase the oxygen content of water, usually with the introduction of air into the system; see aeration

P

Palmate: arrangement where leaflets (small leaves) radiate from a central point; similar to fingers radiating from the palm of the hand

Parasite: an organism that survives by feeding on, damaging or deriving nutrients from another organism

Pathogen: an organism that causes disease to another organism

Pathology: the study of pathogens

Pelagic: referring to deep, cold water; see hypolimnion

Perennial: a plant that requires multiple years or seasons to complete its entire life cycle; compare to annual

Petiole: the "stalk" attaching a leaf to the stem of a plant

Photolysis, photolytic: the breakdown or chemical decomposition of a compound induced by light

Photosynthesis: the daytime-only process by which plants use carbon dioxide to convert sunlight into energy and oxygen

Phytoplankton: tiny, free-floating photosynthetic aquatic organisms; examples include diatoms, dinoflagellates and some species of algae

Pigment: a substance that produces a distinct color in a plant; may have protective properties

Pinnate: resembling or arranged like a feather

Piscivorous: fish-eating

Pistillate: a flower bearing female reproductive structures and lacking male reproductive structures; compare to staminate

Plankton: very small free-floating aquatic organisms; examples include phytoplankton and zooplankton

ppb: parts per billion (1 in 1,000,000,000)

ppm: parts per million (1 in 1,000,000)

Precipitate: settle as a solid to the bottom of the water body

Precipitation: a chemical reaction or process that reduces the solubility of a substance and causes it to precipitate

Predation: consumption of an organism (prey) by another organism (predator) Pristine: natural; not affected by human activity

Productivity: the trophic state of a lake (biological productivity) or the amount of organic matter produced (plant productivity)

Propagation: the act of creating new plants through sexual or vegetative means

Propagules: vegetative or sexual structures with the ability to create new plants; examples include turions, tubers, bulblets, fragments, winter buds and seeds

Protozoan: a single-celled microscopic organism; examples include amoebas and ciliates

Psyllid: an insect in the family Psyllidae; also called jumping plant lice

Pupa: the stage in insect development between larva and adult; pupae are usually protected within a hard cocoon or case

Q

Quiescence: a resting state

R

Ramet: a new plantlet formed by vegetative means; often borne on a runner or stolon

Recolonization: the re-establishment of a species that was previously found in a system but disappeared

Registrant: the organization responsible for the registration of a pesticide with the US EPA

Reservoir: a man-made body of water used for water storage, flood control, hydropower, recreation or other anthropogenic activities

Residue: any substance in food, water or an organism that occurs as a result of application of a pesticide

Resistant: the ability of an organism to survive or be unaffected by a stressor such as a herbicide; compare to susceptible

Respiration: a process in which plants take up oxygen and release carbon dioxide

Rhizome: modified plant structure that grows underground and has buds that can produce new plants

Richness: the number of distinct species present in a system

Riparian: relating to the bank or shoreline of a body of water

Rootstock: the roots, crown and rhizomes of a plant

Rosette: plant growth form where leaves radiate from a central point or crown instead of being attached to a stem

Runner: see stolon

S

Salinity: measure of the amount of salt in water

Scour: to clear a channel or remove sediment as a result of wave action, current or flow

Secchi disk: a circular disk divided into black and white sections and used to measure water clarity or transparency

Sediment: the soil or organic material at the bottom of the water body

Sedimentation: the process of accumulating sediment, usually as a result of wave action, erosion, reduced water flow in plant beds or decaying plant material

Seedbank: seeds that fall to the sediment and provide a source for new plants in future seasons

Selective: a herbicide that controls certain plants while leaving others unharmed

Senescence: plant death

Serrated: with toothed margins similar to the blade of a saw

Shoots: upright plant stems

Short-day: a condition where daylength is less than 12 hours in length (winter in the US)

Species richness: the number of different plant or animal species in a defined area

Specificity: the ability of a herbicide to selectively control target plants without causing significant damage to nontarget plants

Spores: reproductive structures produced by ferns such as salvinia

Stamen: the pollen-bearing male reproductive structure of a flower

Staminate: a flower bearing male reproductive structures and lacking female reproductive structures; compare to pistillate

Stolon: a stem-like structure or shoot that creeps along the surface of the soil or sediment; also called runner

Stratification: a layered configuration within a body of water whereby distinct and separate upper (epilimnion), middle (metalimnion) and lower (hypolimnion) layers are evident

Structure: referring to the array of architectures provided by different plants, logs, brush piles and rocks in fish habitats

Submersed: a plant that grows mostly or entirely under water

Subspecies: a division within a species to designate a group of plants that differ substantially from other members of the species

Substrate: see sediment

Surfactant: short for “surface-active agent”; a detergent-like substance that reduces surface tension and increases herbicide coverage and penetration into plant stems and leaves

Susceptible: an organism that is damaged or killed by a stressor such as a herbicide; compare to resistant

Systemic: a substance that moves throughout an organism via translocation through vessels in plants

T

Tannins: acidic yellow to brown substances derived from plant materials such as tree bark, roots, leaves and tea

Taxonomy: a system used to categorize, describe and identify organisms

Technical grade: the purest, most concentrated form of an active ingredient

Temperate: a climate that is warm in the summer and cold in the winter

Terrestrial: not flooded or inundated

Thermocline: the metalimnion or center layer of water in a stratified lake; the most extreme temperature changes occur in the thermocline as opposed to the upper (epilimnion) and lower (hypolimnion) layers

Topped-out: a phenomenon where submersed plants such as hydrilla reach the surface of the water and form dense mats or canopies that reduce penetration of light and oxygen

Toxicant: a substance used to damage or kill an organism

Translocation: active process of movement of substance within and throughout a plant

Triploid: an organism with three sets of chromosomes; usually sterile and unable to reproduce by sexual means

Trophic: related to nutrition and nutrient levels; productivity

Tuber: a vegetative propagule produced in the sediment to facilitate reproduction and overwintering

Turbidity: the degree to which water clarity is reduced by suspended particles, tannins, algae and other substances; compare to clarity

Turion: a propagule produced in the leaf axils or compressed apical buds of hydrilla to facilitate vegetative reproduction, overwintering, survival and spread

U

Upland: see terrestrial

V

Variety: a division within a species to designate a group of plants that differ substantially from other members of the species; similar to subspecies

Vascular plant: plant with a specialized internal transport or vessel system; sugars are transported in the phloem, whereas water and nutrients are transported in the xylem

Vector: an organism that transmits a disease-causing pathogen

Veliger: snail larvae

W

Watershed: the entire drainage area of a river or the catchment area of lakes

Wetland: an area that is inundated or saturated for long enough periods to support plants that are adapted to living under saturated soil conditions

Whorled: with leaves arranged in groups of three or more at a node

Winter bud: compressed apical bud; similar to turion

Z

Zonation: the separation of areas within an ecosystem into specific zones, with each zone having distinct characteristics that distinguish it from other zones

Zooplankton: microscopic aquatic animals and larvae which usually feed on phytoplankton

More than fifteen years ago, a group of companies formed a nonprofit foundation to address increasing problems with invasive aquatic weeds in complex, multiple-use ecosystems.

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1. Providing information to the public on the benefits of conserving aquatic ecosystems. This involves various operationally sound methods which are appropriate for a particular water body to achieve the objectives of a sound management plan. This includes the appropriate use of EPA registered aquatic herbicides and algicides. The foundation has produced **Biology and Control of Aquatic Plants: A Best Management Practices Manual**, which has become one of the most widely read and used references in the aquatic plant management community. This document can be downloaded from our web site (www.aquatics.org), and illustrates the various ways that aquatic plants can be managed – biological, mechanical, physical, chemical, etc.

2. Providing information and resources to assist regulatory agencies and other entities making decisions that impact aquatic plant management. This goal is partially accomplished by providing independent experts on request to address specifically defined issues. Similarly, AERF has sponsored seminars and symposia throughout the United States on aquatic plant management issues. AERF also assists state and local agencies by providing travel grants for regulatory personnel to participate in aquatic-related professional meetings.

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Biology and Control of Aquatic Plants: A Best Management Practices Handbook, Third Edition

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Biology and Control of Aquatic Plants: A Best Management Practices Handbook is the third edition of a handbook produced by the not for profit Aquatic Ecosystem Restoration Foundation (AERF). The mission of the AERF is to support research and development which provides strategies and techniques for the environmentally and scientifically sound management, conservation and restoration of aquatic ecosystems. One way the Foundation accomplishes this mission is by producing this handbook to provide information to the public regarding the benefits of aquatic ecosystem conservation and aquatic plant management. The first and second editions of this handbook became some of the most widely consulted references in the aquatic plant management community. This third edition has been specifically designed with water resource managers, water management associations, homeowners and customers and operators of aquatic plant management companies and districts in mind. Our goal in preparing this handbook is to provide basic, scientifically sound information to assist decision-makers with their water management questions.

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Appendix E.4: General descriptions of AU stream and lake groups used to analyze potential cumulative impacts.

AENEAS LAKE Aeneas Lake is located in Section 25 T37N R26E. The lake measures 52.6 acres and is banded by a narrow strip of vegetation. An intermittent creek provides inflow, but there is no outflow. The lake is surrounded by some residential development and undeveloped lands within a matrix of agriculture, orchards, and range lands. A public access boat launch is operated by WDFW in the SE corner of the Lake and a common open space exists in the NE corner adjacent to a short plat.

ALBRIGHT LAKE Albright Lake, also known as Peninsula Lake, is located in Section 7 of T35N R26E with an area of 21.4 acres. The lake is undeveloped and surrounded by WDFW lands to the southwest and private range lands to northeast. There is a developed access point located in the SW corner on WDFW property. Vegetation around lake is limited and the alkaline water chemistry cannot support fish life.

ALKALI LAKE Alkali Lake is located in Section 22 of T35N R26E. Alkali Lake is a kettle lake with an area of 63.8 and a shoreline perimeter measuring 2 miles. The lake is surrounded by private land that is roughly 1/3 developed amidst undeveloped lands. No developed Public access is available on the lake. The water in Alkali Lake is considered alkaline, displaying a greenish blue tinge and its water chemistry cannot support fish.

ALTA LAKE Alta Lake is located in Section 15, T29N R23E. Alta Lake is 219.6 acres and measures about two miles long and half mile wide. The lake sits in a coulee at the base of steep forested and shrub steppe terrain. The lake contains no inflow or outflow. The north and eastern shoreline houses Alta Lake State Park, where a campground and trails provide visual and direct access to the lakeside including two boat launch ramps. Residential development for seasonal and full time homes exists along the western, northeastern and southern shores. The USFS owns a large portion of the east and west shorelines at the south end of the lake. Alta Lake is used for fishing, motor boating, and swimming.

ANTOINE CREEK Antoine Creek joins the mainstem of the Okanogan River at RM 61.2. The Antoine Creek group reaches approximately 5 miles and is oriented in an east-west direction. The creek drains a dry landscape of shrub and rangelands, with some irrigated fields through a narrow, steep-sided canyon noted for erosive gullies exacerbated by hoof sear. Management issues include bank erosion, noxious weeds, and heavy grazing.

BEAVER CREEK The Beaver Creek group includes those shorelines below the 20 cfs point in the lower 9 miles of the Beaver Creek. Beaver Creek is a high-moderate gradient, north/south creek draining mountainous terrain and undulating range lands. The creek enters the Methow River at RM 35. The shorelines are privately owned with the exception of the middle and upper reaches that lie within Department of Fish and Wildlife and Okanogan National Forest ownerships. Land uses along Beaver Creek are dominated by open range grazing; some irrigated fields and dispersed rural residences. There is no public access to the creek within the lower 7 miles except for that provided at bridge crossings.

BIG TWIN LAKE Big Twin Lake is located in Section 15 T34N R21E. A kettle lake, Big Twin Lake is a deep depression lined by steep slopes to the SW, S, and East, while the Northern shoreline is a more gradual slope. It is fed by groundwater and supports a trout fishery. The lake measures 65.4 acres with a perimeter of 2 miles. WDFW owns a large portion of shoreline in the SW corner for fishing access as well as a boat launch in the NE corner of the lake. The surrounding land uses are rural residential and a private RV campground.

BLUE LAKE Blue Lake is located in 22 of T39N R27E. This kettle lake measures 205 acres. The lake is surrounded by private land with only one structure on the shoreline to date. There is a WDFW access point at the SW corner of the lake. The water in Blue Lake is considered alkaline, displaying a greenish blue tinge and its water chemistry cannot support fish.

BLUE LAKE (SIN) Blue Lake is located in Section 22 T37N R25E. The lake measures 205 acres in area. It is an artificial reservoir composed of a series of smaller natural lakes along the Sinlakehin River into one feature. The entire shoreline is owned by WDFW and there are four public access points, three with trailer launch ramps, and one with a hand launch site along the eastern shoreline.

BONAPARTE CREEK Bonaparte Creek drains roughly 98,738 (HUC 10) – 102,120 acres of sparsely developed range lands. This 4th order stream flows 24 miles from its headwaters in the east and winds westward to meet the Okanogan River at the city of Tonasket at Okanogan RM 56.7. The creek begins at a gentle gradient supporting a variable width of riparian vegetation and wetlands in its upper reaches. A complex wetland/riparian band can be found at its confluence with Peony Creek. The creek then flows through steeper terrain into a narrow canyon eventually cascading over a natural fall at river mile 1.0– just east of the city. This is where the Bonaparte Creek group ends. The falls create a natural barrier to fish migration, though resident trout and sculpin can be found above the falls. The entire creek is surrounded by private land, primarily used for agricultural grazing. The canyon section holds high potential for wildlife in a relatively undeveloped environment although issues related to winter grazing, hoof sheer erosion, lack of cover and invasive species were noted in the Sub Basin Plan. No known public access exists along its shorelines although the canyon is visible in the vicinity of the falls via an unofficial overlook at the Hwy 20 Bridge.

BONAPARTE LAKE Bonaparte Lake is located in Section 17 T38N R30E at an altitude of 3550 ft. It measures 151.7 acres. The lake is connected to a chain of small ponds and wetlands that serve as the headwaters of Bonaparte Creek. The shoreline is forested and owned mostly by Okanogan National Forest with exception of the SE corner that is owned by the state. A campground and boat launch in the southern tip is managed by ONF. There is also a small resort with lake access and one dock is located at a Boy Scout camp along the northern shoreline.

BOOHER LAKE Booher Lake is located at T35N R26E. The surface area of the lake is variable depending on hydrologic fluctuations, with a range of 18 – 29 acres. The lake is surrounded by private agricultural range lands with no structures in the shoreline to date. Pine Creek, and intermittent creek provides inflow to the lake; no outflow exists. No public access exists on the lake.

BREWSTER Shorelines in the Brewster Group include the banks of the Columbia River along the Wells Pools running from RM 527-536 as well as upstream along the Okanogan River where it meets the Columbia. These shorelines are within the city of Brewster and are characterized by tree fruit agriculture, residential and commercial uses. The majority of the waterfront shoreline area is owned by the Douglas County PUD. Access can be found at the city park, including two docks and a launch, and along the river walk in downtown Brewster. The shoreline along this portion has been greatly modified as part of the development of the Wells Dam impoundment. The entire shoreline has been stabilized with rip rap and supports a narrow band of riparian species in some areas. Fluctuations of the pool create variable habitat zones along the water's edge, and some side bar islands and wetlands do exist; however, the shoreline has been greatly simplified and is more reflective of lakeside environments than river systems.

The southern portion of this group encompasses the shoreline area parallel to US 97 and the BNSF rail road along the Columbia River between Brewster and Indian Dan Canyon, RM 529- 527. It is almost entirely owned by the Douglas County PUD. Those portions not owned by the PUD are composed of residential subdivisions near Brewster and some orchards and industrial uses related to agriculture and transportation. The shoreline through this section has been highly altered from hydroelectric development and includes heavy armoring to support and protect this vital transportation corridor for the railroad and highway. There is one developed access point operated by the PUD near RM 529.

BROWN LAKE Brown Lake is located in Section 7 T34N R26E. The lake measures 61.5 acres. It is a very shallow bottomed lake (14 ft max. depth) that emerges at the confluence of two unnamed creeks. Outflow is into Johnson Creek, a tributary to the Okanogan River. Little to no riparian vegetation exists, but the lake does support emergent aquatic vegetation along its edge. The lake is surrounded by open range land, with no formal public access.

CARLTON - TWISP The Carlton-Twisp group of the Methow River extends south from Twisp near the Hwy 20 Junction to Carlton -- RM 37.5 – 27.6. The upper portion of this group meanders through a wide, active channel, creating large gravel bars and mid-channel islands. As the river approaches Carlton the stream channel narrows and is surrounded by steep erosive bluffs. Riparian vegetation can be found along stable banks and wide bars. Bank stabilization has occurred throughout this group for road and land protection. There is no developed public access within this group. An informal public access exists between RM 33-34 on WDFW property. The surrounding land uses include rural residential and agriculture.

CARLTON LAMIRD The Carlton LAMIRD (Limited Area of More Intense Rural Development) group includes a 1 mile reach of river that encompasses the population center of Carlton centered on RM 27. Carlton houses a post office, RV park, motel, restaurant, general store and fire station, and shoreline uses include public access and dispersed rural residential development. A WDFW fishing access site serves this area adequately for access. It is a popular launch site for commercial and private float trips with a great swimming beach that brings in visitors to Carlton.

CHEWUCH RIVER The Chewack (Chewuch) River group flows southwest from high elevations in the Pasayten Wilderness on USFS land through sparsely populated residential and agricultural lands until it meets the Methow River in the town of Winthrop. The Lower Chewack Watershed (HUC 10), which encompasses all shorelines designated in this SMP, drains nearly 200,000 acres of mountainous terrain through a surrounding landscape of forested slopes with patches of meadows in the highlands and shrub-steppe terraced hillsides in the lower reaches. Riparian cover is relatively continuous throughout the reach. There are 5 diversions for irrigation and extensive portions of the river's banks, including the alluvial fans of receiving streams have been rip-rapped for flood control. Public access along the Chewack is plentiful above RM 35 where various developed campgrounds and day use sites are managed by the USFS and WDFW. Informal and undeveloped access sites also exist. A new park, "Sa Teekh Wa", in the Town of Winthrop also provides shoreline access via a pedestrian bridge and riverfront trail. Limited access exists in the more heavily developed areas between RM 28 and 35, with the exception of one WDFW non-motorized (walk-in) location and a scattering of privately owned community open spaces. The Okanogan County Outdoor Recreation Plan identifies "river trails" as a high priority and this lower portion of the Chewack River has no trail system.

CHOPAKA LAKE Chopaka Lake is located in Section 4 T39N R25E. The lake measures 68 acres. It sits in a narrow trough with a north-south orientation and surrounded by steep forested slopes. The lake flows out into Chopaka Creek, a tributary of Sinlahekin River. The southwestern 1/3 is privately owned, but the remainder of the shoreline is publicly owned with one WDFW access and a BLM campground and access along the western shoreline.

CONCONULLY LAKE Conconully Reservoir is located in Section 18 T35N R25E. The reservoir is an artificial lake impounded by a USBOR dam built just below the confluence of the West and North Forks of Salmon Creek in 1910. Used for irrigation storage, the lake now supports broad recreational and residential uses. Surrounding land uses include open range, agriculture, urbanization and forest lands. Most of the land around the lake is owned by the federal Bureau of Reclamation with much of the north and western shorelines leased to the owners of private cabins and several small resorts. Public access is found along the NE corner at Conconully State Park, as well as at the southern shoreline at the dam.

CRAWFISH LAKE Crawfish Lake is located in Section 35 T35N R29E. The lake is 80 acres in area. The lake sits in a shallow basin amidst a forested landscape of gentle slopes. About 1/3 of the shoreline is privately developed with recreational cabins, including some docks. Approximately half of the shoreline lies within the bounds of the Colville Indian Reservation. Public access is available at the northeast corner in USFS campground.

DAVIS LAKEDavis Lake is located in Section 20 T34N R22E. The lake, 39.8 acres in area, is fed by an unnamed creek the flows in from the east; no outflow exists, though the lake does terminate to the north in a wetland. There is a public boat launch operated by WDFW at the northern tip of the lake and the southwestern quarter of the lake is owned by the federal government. A small RV park occupies the eastern shoreline. Otherwise, the lake is privately owned and surrounded by open range lands characterized by shrub-steppe habitat.

DUCK LAKE Duck Lake is located in Section 10 of T34N R26E. The lake is in a closed basin with no outflow. However it is fed by Johnson and Salmon Creeks as well as supplemented by irrigation diversions. The water is used for irrigation. Surrounding land uses included limited residential development and open range land. The margins of the shoreline support some woody vegetation. There is no public access.

EAST OSOYOOS The East Osoyoos group is differentiated from West Osoyoos based on its relative lower level of development. While there are some undeveloped portions of the shoreline, the shoreline still remains primarily in agricultural use. In recent years there has been an emerging resort development as agricultural lands are converted. Access is on this side of the lake to private parcels and resorts. The entire lake is within the city of Oroville with much of the existing development served by city water and a growing number of sewer connections.

EVANS LAKE Evan Lake is located in Section 28 of T35N R26E. It is a silt bottomed alkaline lake measuring 32.7 acres. The shoreline is entirely privately owned with no public access or road for access. Surrounding land uses include open space rangeland and one seasonal cabin.

FANCHER DAM RES Fancher Dam Reservoir is located in Section 35 T39N R28E. The lake is 26 acres in area. The reservoir is impounded by a dam built in 1923 at the headwaters of Antoine Creek for livestock watering. The southern shoreline and outflow area is heavily forested. There are no public access sites, as the shoreline is entirely privately owned.

FIELDS LAKE Fields Lake is located in Section 26 of T40N R29E. The lake measures 25 acres. The sinuous shoreline of the lake is lined by a narrow band of forested vegetation. The lake is fed by a perennial stream as part of the headwaters of Mary Ann Creek, a tributary to Myers Creek. The shoreline is owned by a single private ownership and has no public access.

FISH LAKE Fish Lake is located in Sect 22 T36N R25E. The lake measures 101.6

acres. The lake is fed by Gibson Creek and sits in a narrow coulee where the outflow forms Coulee Creek. The northern shoreline is a steep, rocky slope with little vegetated cover. The southern and western shorelines support forested and wet meadows. Public access is provided via a road that circumscribes the lakeshore and campgrounds along the southern shore. The entire shoreline is owned by the USFS or WDFW.

GOLD CREEK Gold Creek drains a narrow valley of shrub-steppe and forested slopes in the Lower Methow Sub-watershed (HUC 10). The drainage flows west to east and empties into the Methow River at RM 22.7 and the group includes roughly 4 ½ miles of shoreline. The lower 3.5 miles of the creek has been channelized with rip rap, restricting lateral channel movement (Methow Subbasin Plan, 2004). This group is surrounded by rural residential property that supports grazing and timber harvest. There is no public access along the creek other than an undeveloped USFS site located just east of the Middle Fork Gold Creek Road.

GREEN LAKE Green Lake is located in Section 13 T34N R25E. The surface area measures 45 acres. The lake sits in a narrow forested valley and the lake is oriented north-south with an average width less than 500 ft. WDFW operates an access site on the eastern shoreline with a boat launch while the remaining shorelines are privately owned and undeveloped.

HORSESHOE LAKE Horseshoe Lake is located in Section 17, T36N R26E, just east of Albright (Peninsula) Lake. It is an alkaline kettle lake measuring 36 acres. The majority of the shoreline is surrounded by open rangeland, though the southern boundary has been subdivided for seasonal homes. There is no established public access; however, there is a large parcel of state-owned land in the northwest corner of lake.

KEYSTONE - TONASKET The Keystone-Tonasket Group extends south along the Okanogan River from the southern boundary of Tonasket at RM 56.1 – 52.3. This area occupies a broad floodplain with rural residential and agricultural uses. Residential and agricultural uses have minimized the extent of riparian vegetation as well as the complexity of the channel. The channel is primarily a single course though some mid-channel islands do exist, suggesting a degree of dynamism through this group. There are no developed public access points throughout this section.

KEYSTONE CANYON The Keystone Canyon group extends from the Janis Bridge at RM 52.3 to RM 41.7 just north of Riverside. The river is confined to a narrow, steep canyon through much of this group, limiting the extent of a natural floodplain. Where a floodplain does exist, agricultural fields occupy the landscape, confining the river to a single channel. Much of this reach lacks robust riparian vegetation or channel complexity due to natural topography and agricultural conversion. Public access does not exist outside of informal right of ways or bridge crossings.

LAKE PATEROS Shorelines in the Lake Pateros group include the banks of the Columbia River along the Wells Pool running downstream from RM 523 to the confluence with the Methow River and extending up the Methow to RM 1.7. It is characterized by the inundation zone of the Wells Pool along the Columbia and the Methow within the urban growth boundary of Pateros. This area has been heavily altered by inundation and filling. The entire shoreline is composed of up to nine feet of fill and is therefore supported by continuous rip rap along the shoreline. The majority of the waterfront shoreline is owned by the Douglas County PUD. Native riparian vegetation can be found in portions of the Methow River where mid-channel islands, bars, and wetlands have been established for wildlife. The majority of the group, however, is dominated by residential lawns or parkland landscaping along the PUD lands. Residential and commercial development line the north bank of Lake Pateros and the Methow River while public access is provided in the at numerous PUD locations and city parks. WDFW operates 2 access sites in this reach, including a boat launch and fishing site. It is a popular site for all types of watercraft including rafts, kayaks, motorized boats and jet skis. The WDFW site on the south bank of the Methow across from Pateros is the primary take-out site for commercial float trips on the lower Methow River.

LEADER LAKE Leader Lake is located in Section 16 T33N R25E. The lake area measures 155 acres and the perimeter is 4 miles in length. The lake is a natural lake supplemented by diversions from Loup Loup Creek and artificially controlled by a dam built circa 1910, but would otherwise drain into Tallant Creek. The shoreline is surrounded by open range lands and sparsely forested hillsides. Approximated 1/3 of the western shoreline is publicly owned and operated by WDFW for fishing, boating, and camping access.

LEMANASKI LAKE Lemanaski Lake is located in Section 3 T37N R25E. The lake measures 20 acres. There is a private dam that impounds the lake to supplement water supply. The lake is privately owned with no public access other than informal ROW access along the western shoreline.

LITTLE TWIN LAKE Little Twin Lake is located in Section 14 T34N R21E. Similar to Big Twin Lake, the water is ground fed and sits in a steep basin. Little Twin Lakes shares a boat launch access site with Big Twin Lake and is otherwise surrounded by private community open space owned by the surrounding rural residents.

LOST CREEK Lost Creek flows in a northeast direction from T34N, R30E to T35N, R31E approximately 7 miles. The creek lies in a V-shaped basin and drains a gently sloping, forested landscape almost entirely owned by the ONF before it enters into the West Fork of the Sanpoil River. Surrounding land uses are forestry and open rangelands. No developed public access exists.

LOWER METHOW The Lower Methow Group extends from RM 12.8 beginning at the southern boundary of the population center known as Methow to the inundation zone of Lake Pateros at RM 1.7. This shoreline landscape is characterized by steep bluffs that form narrow reaches of canyon topped by wide benches that support rural residential development and orchards. Sandy point bar beaches are formed through wider reaches in this section and this group is popular for white water rafting. It is served by informal access points at HWY 153 bridge crossings at RM 5 and 6 and an access using County road right of way at the Burma Road Bridge. USFS owns parcels along the shoreline between RM 9-10 which hold potential for access, however, only a single developed access point exists (A WDFW site) between Methow and the WDFW sites on Lake Pateros as the majority of this reach is privately owned.

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LOWER OKANOGAN The Lower Okanogan group extends from RM 16.7 of the mainstem of the Okanogan River, and the tributary, Loup Loup Creek, downstream to the confluence with the Columbia River at the northern boundary of Brewster. This reach of the river is impounded by Wells Dam on the Columbia River, creating a large, slow moving pool. The shoreline is dominated by agricultural uses, primarily orchards and hay fields. Riparian vegetation is stable due to the infrequent scour and flooding in this zone caused by the impoundment. The banks are silt and sand. The river divides Okanogan County shoreline jurisdiction from the Colville Confederate Tribe's jurisdiction on the eastern shoreline. Public access along the Lower Okanogan can be found at RM 0.5 at a WDFW fishing access and again at RM 4.5 at a PUD site. Between RM 4.5-16.7 no developed access exists. Informal access can be found along Monse River Road in the lower few miles, but otherwise this group has limited access. Loup Loup Creek contains native resident trout and steelhead but suffers from de-watering from irrigation diversions farther upstream. Eastern brook trout have likely out-competed native bull trout in the system. Anadromous fish cannot pass beyond RM 1 on Loup Loup Creek where a natural falls occurs.

LOWER SALMON The Lower Salmon group extends from approximately RM 4.3 at the Okanogan Irrigation Diversion Dam to the Confluence with the Okanogan River. This portion of Salmon Creek does not satisfy the 20 cfs minimum for inclusion in the SMP. However, restoration efforts by the Colville Confederated tribes are securing 10 cfs for Steelhead habitat.

LOWER SIMILKAMEEN The Lower Similkameen group includes those shorelines adjacent to the Similkameen River from RM 8.8 at the Enloe Dam downstream to the vicinity of the old rail trestle (RM 6.5). This is a turbulent section of river incised into a steep, sparely vegetated bedrock canyon.

LOWER SINLAHEKIN The Lower Sinlahekin group reaches from RM 10 on the Sinlahekin River at the confluence with Toats Coulee to RM 6.5 where the river empties into Palmer Lake. The river is highly sinuous and historically would have been multi-channeled. However, surrounding agricultural uses have restrained the river to a single channel. Nonetheless, at the Toats Coulee confluence, a wide wetland complex exists. No public access is found within this portion of the river.

LOWER WELLS POOL Shorelines in the Lower Wells Pool group include the banks of the Columbia River along the Wells Pool running from RM 517-522 just south of the confluence with the Methow River. The shoreline here has been greatly modified by inundation from hydroelectric development. Land uses through this group include agriculture and grazing and the shoreline is largely owned by the Douglas County PUD. One developed WDFW public access is located near RM 518.

MALOTT LAMIRD The Malott LAMIRD group includes those shorelines within this unincorporated community along the main stem of the Okanogan River. The Okanogan River shorelines in the LAMIRD contain residential and some limited commercial development. Shorelines in Malott support rural, low density residential and agricultural uses.

MAZAMA The Mazama group begins below where Early Winters Creek flows into the Methow River just upstream from the population center known as Mazama. This group extends downstream through a wide glacially carved valley to RM 50.9 just west of the Town of Winthrop. In addition to shorelines along the mainstem, this group also includes shorelines associated with Wolf Creek extending approximately 2 miles upstream to the 20 cfs mark. Major tributaries include Goat Creek, Fawn Creek, and Wolf Creek. The Methow River is very dynamic through this group, supporting a wide flood plain and channel migration zone with robust riparian forests, side channel habitats, and ox-bow wetlands. Despite the high level of ecologic integrity in this group, shoreline modifications have been made for highway and property protection. Surrounding land uses are characterized by irrigated hay fields, rural residences, seasonal homes, and small-scale resorts and rentals. Access to the river includes Big Valley Ranch, a WDFW property; the Community trail in Mazama; and Early Winters Campground at the confluence of Early Winters Creek and the Methow River. There is also informal access points along road right of ways and at private common areas created via short and long plats.

MEDICINE LAKE Medicine Lake is located in Section 5 T35N R26E. It is an alkaline, kettle lake measuring 43.1 acres. The shoreline is entirely privately owned with no public access and surrounded by open range land.

METHOW - CARLTON This group runs from the population center of Carlton downstream to the community of Methow, RM 26.7 – 13.3. This group is characterized by a narrowing of the valley floor and numerous steep, forested tributaries that empty in the mainstem of the Methow River, including Cow Creek, Libby Creek, Gold Creek, McFarland Creek, and French Creek. Irrigated pastures and cropland, orchards, rangelands, and rural residential uses border the shorelines. Riparian vegetation is limited to narrow bands along the often steep banks, though some point bars do support vigorous groves of gallery forests. Highway modifications have hardened and confined the banks around most of the large meanders. There are only two developed public access points within this group, though many informal and common areas provide local access to residents. Public lands along the shoreline between RM 26-24 could hold potential for more access.

METHOW LAMIRD The Methow LAMIRD (Limited Area of More Intense Rural Development) group includes a ½ stretch of shoreline that falls within the small community known as Methow and centered around RM 13. Point bars support some riparian vegetation along the shoreline through this group, but much of the river is confined by steep banks in this section with little riparian cover. Shoreline ownership through this section is privately owned (except for a parcel owned by the Pateros School District - Methow Community Center) and primarily residential and agricultural in nature, although a private RV campground lines the north eastern shoreline. Resort and residential development is rapidly occurring in the vicinity of Methow which may cause an increase in demand for river access and services in Methow. The nearest public access is located at the French Creek Road junction where Hwy 153 crosses the river just north of the community.

MIDDLE METHOW The Middle Methow group extends from RM 47.5, just south of the town of Winthrop to the RM 41.9 to the Town of Twisp. This extremely active portion of river contains wide meanders and supports a dynamic channel with abandoned and active side channels and mid-channel islands. Riparian forests of mixed cottonwoods and Ponderosa pine line the variable sloped banks and gravel bars. The surrounding land uses are primarily irrigated alfalfa fields, small-scale row crops, and rural residential homes, though there is an airport and some industrial uses as well. Open spaces in this section of river valley support large numbers of mule deer. Public access is limited to informal access along highway right-of-ways, and common areas; that is, no developed public access exists within this group.

MIDDLE OKANOGAN The Middle Okanogan group extends downstream from RM 23 in the vicinity of Barnholt Loop to just below RM 20 north of Malott. The shoreline area is in transition from resource to residential uses and has some areas with extensive floodplain.

MIDDLE SIMILKAMEEN The Middle Similkameen River group runs northeast from the confluence with Palmer Creek at RM 19.5 then arcs downstream to the southeast where it ends at Enloe Dam. This portion of river sits in a relatively wide valley with a low gradient and supports an active floodplain. Surrounding slopes include shrub-steppe and forested habitats, while agricultural fields occupy first and second flood terraces. Abandoned mines and mill sites and small-scale gold dredge mining occurs within this reach of the river. It is believed that Salmon never reached this portion of the Similkameen. Riparian cover is limited by agricultural use. Public access occurs at informal pull-outs along the Loomis-Oroville Rd with one primitive BLM campsite located at Similkameen Camp.

MIDDLE SINLAHEKIN RIVER The Middle Sinlahekin group runs north from RM 16.5 -10. It drains a forested valley and supports a flood plain. This group ends just below the confluence with Toats Coulee Creek. At the confluence and below, a wide wetland complex exists. Surrounding uses include agriculture, forestry, and open range as well as public access.

MILES LAKE Also known as Big Buck Lake, Miles Lake is fresh water lake located at T34N R21E. The outflow into an unnamed creek (Frost Creek) is completely diverted into irrigation canals that serve rural properties along the Twisp River valley. The lake is surrounded by range land and one residential unit. WDFW owns the southern 1/3 portion of the lake, while the remaining 2/3rd is privately owned.

MOCCASIN LAKE Moccasin Lake is located in Section 17 T34N R21E. This 32 acre lake is a privately owned lake with no public access but does have a private dock. The lake is surrounded by rangelands and protected via a private conservation easement.

MOLSON LAKE Molson Lake is located in Section 8 T40N R29E and is immediately SW of Sidley Lake where it separated by a road bed. The lake measures 20 acres. This is a shallow (maximum depth 20ft), silt bottomed lake that supports aquatic plants. The surrounding land use is open range land. There is no development along the shoreline. Public access is provided at NW corner of the lake at a WDFW site.

MUSKRAT LAKE Muskrat Lake is located in Section 15 T39N R29E. The lake measures 40-45 acres depending on water levels. This lake is an extremely shallow (maximum depth 6 ft), silt bottomed lake subject to de-watering. It is surrounded by private agricultural and range lands. There is little potential for public access given the water depth and quality, though options for habitat enhancement may exist.

OKANOGAN CITY The Okanogan City group includes those shorelines along the main stem of the Okanogan River near the City of Okanogan as well as lands downstream along the Okanogan River to the vicinity of Barnholt Loop. Salmon Creek is the major tributary for this section river. However, Salmon Creek does not meet the 20 cfs minimum required for designation of its shoreline due to irrigation withdrawal 4.3 miles upstream. The main stem of the Okanogan River through this group is confined to a single channel by channelization and armoring for levees and flood control. A narrow band of riparian vegetation exists throughout the group however, providing a green buffer. Land uses span the range of urban development from rural residential, commercial, educational, institutional and industrial uses throughout this group. Public Access exists at the Alma City Park, at the entrance to the Wastewater Treatment Plant and informal access points exist at Legion Park, at city owned property surrounding the treatment plant and along road rights-of-way and bridge crossings. Overall, access to the riverfront is limited within the City limits.

OMAK - RIVERSIDE The Omak-Riverside group extends from RM 40 – 35. This portion of river is primarily constrained to a single wide channel with very little channel complexity. There are two side channel islands located at RM 35 and 38 that support riparian vegetation. Shoreline riparian vegetation is limited by agricultural development throughout much of the group, however, much of the areas between the railroad and river along the eastern bank contains riparian vegetation. Land uses include rangelands, agriculture, industrial and rural residential. There is no developed public access although there are right of ways that are used as informal access points.

OMAK CITY The Omak City group runs from near the northern boundary of Omak downstream to the city of Okanogan's northern boundary. The river through Omak takes on a variety of characteristics ranging from free flowing and complex at the lower portion to Corps of Engineers built levees and steep bluffs abutting the river through the heart of the city. Along Aston Island side channels support active wetlands. This wilder portion gives way to a constrained portion where a levees line both sides of the shoreline through the downtown where uses include residential and commercial developments. The northern reaches through Omak and north support rural residential development amidst a unique landscape pocked by massive boulders in the floodplain. Riparian vegetation is typically established between the armored banks and the river throughout this reach. The Omak Eastside Park and Stampede Grounds is an important cultural site in this group. Public access exists at the Stampede Grounds as well as at Aston Island and Pioneer Park. The northern portion has limited public access.

OROVILLE CITY Shorelines within the Oroville City group include portions of the Similkameen and Okanogan Rivers upstream of their confluence and within the most heavily developed areas of Oroville. This group is urbanized, yet the river systems maintain a high degree of channel complexity, including wide meanders, wetlands, and side channels. Development along the rivers includes commercial, industrial, and residential uses. WDFW also holds large tracts of land south of the confluence on Okanogan River (Driscoll Island). River access is well provided for in the northern portion of this group on the Okanogan. The southern portion contains two WDFW access sites in the vicinity of the confluence. Lake Osoyoos State Park, located at the outlet of Lake Osoyoos into the Okanogan River provides a developed access and a variety of recreation improvements.

The Similkameen River portion of the group begins where the river emerges from the narrow canyon at the old rail trestle. The river is sinuous and levels out creating large meanders and a well developed floodplain associated with the confluence with the Okanogan River. Surrounding land uses include orchards, range lands, and rural – urban residential at Oroville. Public access is available at the 12th Street Bridge and sewer treatment plant in Oroville.

PALMER CREEK CONFLUENCE The Palmer Creek Confluence group encompasses the confluence of the Similkameen River and Palmer Creek which flows from Palmer Lake. This is area is very complex, sinuous wide floodplain that hosts a complex wetland system of active and abandoned meanders from the Similkameen and Palmer Creek.

Grazing has altered plant composition, but the confluence support a diverse assemblage of riparian and wetland habitat types. There are no public access areas within this group.

PALMER LAKE Palmer Lake is located in Sect 11 T39N R25E. Measuring at over 2,000 acres, this is a lake of Statewide Significance. The shoreline is both privately and publicly owned. The lake is a glacially carved trough fed by the Sinlahekin River. Outflow of the lake is via Palmer Creek which flows into the Similkameen River through a complex, braided wetland system. Surrounding land uses are primarily open range lands with some orchards to the east. The south and western shoreline is a steep, barren hillside with rock outcrops, whereas the north and eastern edges are more gradual and lined with vegetation. Private development along the eastern shoreline consists of permanent and seasonal residences and some private docks. There is a developed boat launch at the southern tip of the lake, a DNR campground and resort near the northern end and other public, undeveloped access points on the west and northern shorelines.

PATTERSON LAKE Patterson Lake is located in Section 19 of T34N R21E. The lake measures 160.3 acres. The lake is fed by Rader Creek and a small impoundment on the northern end maintains water levels where it empties into a series of beaver ponds and a single channel that eventually gets diverted for irrigation. The lake is heavily used for recreational fishing, non-motorized boating, swimming and hiking. There is a resort located on the northern shore with a common dock, as well as a launch site along the eastern shore that is operated by WDFW. Trails for hiking and mountain biking parallel the WDFW lands along the western shoreline while the southern end is privately owned and supports irrigated fields.

PEARRYGIN LAKE Pearrygin Lake is located in Section 36 of T35N R21E. The lake measures 182 acres. The lake is fed by two perennial streams, Pearrygin Creek and an unnamed creek. The outflow is captured for irrigation via canal. The glacially carved lake sits in a narrow valley where it abuts a forested slope to the south and open shrub-steppe habitat to the north. The majority of the shoreline is owned by Washington State Parks and the park is used heavily for watercraft, camping, hiking and fishing. WDFW owns the eastern shoreline, and there are some private in-holdings along the southwest corner of the lake.

RAT LAKE Rat Lake is located in Section 22 of T31N R24E. It is an artificial lake created by an old dam built prior to 1917 for irrigation at the headwaters of Whitestone Creek. Today, it is managed for flood control. Surface area measures 61.2 acres. The eastern shoreline is privately owned while the western shoreline is owned by the federal government. There is small boat launch, operated by WDFW, at the southern tip of the lake at the dam.

RIVERSIDE TOWN The Riverside Town group includes those shorelines along the Okanogan River within and to the south of the incorporated location of Riverside, RM 41.7 – RM 36, including the alluvial fan at the confluence of Johnson Creek. The Okanogan River takes a sweeping S-shaped bend through Riverside where the banks are armored with a levee for flood protection. Riparian vegetation waterward of the levee is intact and robust, but limited to this narrow strip. The surrounding land uses include residential within the town proper and agriculture outside the town center. There are two developed public access sites within Riverside.

ROBERTS LAKE Roberts Lake is located in Section 9 T35N R25E. This shallow bottomed lake measures 34 acres and fluctuates greatly depending on water levels. The shoreline does not support woody riparian vegetation. The surrounding land is privately owned, and the uses are open range; there is no public access.

SALMON/CONCONULLY LAKE Salmon Lake is located in Section 6 T35N R25E. The surface are measures 292 acres. The lake is impounded by a dam along the western edge where an outlet releases water into the North Fork of Salmon Creek where it flows into Conconully Reservoir. The lake sits in a narrow valley trough at an east-west orientation, surrounded by steep forested hillsides. The lake is almost completely surrounded by public lands, including Forest Service and State lands. Land leases for cabins on BOR lands occur along the northern shoreline. Public access is found in the vicinity of the Dam and a WDFW launch site and resort on the northern shore.

SIDLEY LAKE Sidley Lake is located in Section 6 T40N R29E. The lake measures 104.8 acres. This high altitude lake sits a 3660 ft and has an average depth of 17 feet. The northern shoreline has been structurally modified to support Nine Mile Road. The west and SW shorelines have been platted and contain cabins and homes. Docks are present along private lands. Public access is available at the eastern shoreline where a WDFW launch site is shared with Molson Lake. No public beach exists.

SINLAHEKIN HEADWATER The Sinlahekin flows from Blue Lake T37N, R25E and travels northward through a series of ponded, shallow pools connects by a meandering channel of low gradient. This portion of the river is flanked by relatively steep forested banks, but occupies a flat valley that supports flooding and extensive shrub wetlands along the banks. There are numerous WDFW campsites along the river for fishing and camping.

SPECTACLE LAKE Spectacle Lake is located in Section 2 T38N R26E. The lake is 313 acres in area. The lake sits in a narrow valley trough with an orientation east-west. The northern shoreline supports orchards; small resorts and range land at the toe of gentle, bare slopes, whereas the southern shoreline is bordered by steep bluffs of undeveloped ONF land with scattered trees and forests.

TALKIRE LAKE Talkire Lake is located in Section 22 T36N R28E. The lake measures approximately 38 acres when full. The basin lies within Chewiliken Creek and this shallow bottomed basin is prone to de-watering to form more of a wetland. It is entirely surrounded by private, open range lands and has no public access.

TOATS COULEE Toats Coulee is a narrow stream channel draining steep slopes in T39N, R25E. The creek follows an easterly direction and is incised in a V-shaped channel where there is little to no floodplain. South facing slopes support open habitats

of grasslands and shrubs, whereas the northern aspects are forested. Most of the lower reaches of shoreline are privately owned, and undeveloped, whereas the State owns and manages portions of the upper reaches. No pubic access is developed along the creek.
TONASKET CITY The Tonasket City group includes those shorelines within Tonasket. At Tonasket, three tributaries, Bonaparte Creek, Siwash Creek, and Unnamed Creek, flow into the main stem, creating a wide shoreline jurisdiction. Uses include commercial, residential, and some industrial areas in the central group, while agricultural, orchards, and rural residential are found outside. Public access is developed at Lagoons City Park. Informal access exists History Park and at bridge crossings and ROWs, but otherwise is limited in town.

TORODA CREEK Toroda Creek is located in the far NE corner of the county in T39N, R31E. It is a tributary of the Kettle River in neighboring Ferry County. Toroda Creek drains a shrub steppe-forested landscape of gentle to steep slopes. The creek is of moderate gradient supporting a narrow floodplain occupied by agricultural fields and grazing lands. There is no public access along this portion of shoreline.

TWISP RIVER The Twisp River group begins at the Eagle Creek and flows east to a point a couple miles upstream from Twisp, approximately 12 miles. The Twisp River is a major tributary of the Methow River and support anadromous fish. Much of the river has been channelized through diking and riprap for property protection to support surrounding agricultural and residential uses. Despite this, riparian forests are still supported as is a narrow flood plain. The river meanders through a series of terraced benches where surrounding properties are rural residential and agricultural in nature. Public access can be found about 5 miles upstream at WDFW site and at ONF sites. However, the lower reaches are underserved for public access given the proximity to Twisp and the surrounding residential developments.

TWISP TOWN The shorelines in the Twisp Town group include those portions of the Twisp and Methow Rivers within Twisp. The Twisp River portion of this group begins about 2 miles upstream from the Town and is generally unconstrained. As the Twisp River reaches Town, it is stabilized by a flood levee on the southern bank. Where the Methow and Twisp rivers meet, a dynamic alluvial fan from the Twisp inputs large gravels, boulders and cobbles, creating large bars during low water. This area is heavily used by town residents and visitors for fishing, swimming, and beach combing. Surrounding land uses are primarily residential, open space and parks, and a large amount of former industrial and agricultural land. The mainstem of the Methow River is channelized through town and reinforced for bridge abutments at Highway 20. A narrow riparian forest of cottonwoods lines the otherwise steep banks. Public access on the Methow is provided as Twisp park, at the end of E. 2nd Avenue and informal access for foot traffic is found at the Highway 20 bridge. Access on the Twisp is found at the Methow Salmon Recovery Foundation property and at the county road bridge just west of the Town limits.

UPPER METHOW The Upper Methow group begins just upstream of where Lost River joins the Methow River. This portion of river is highly dynamic, draining a vast wilderness landscape of steep forested hills and snow and glacially covered peaks. The river flows in a south east direction where numerous small tributaries and streams contribute sediment and flows. Early Winters Creek enters the system at RM 67.5 creating an alluvial fan where the river meanders through large cobbles and sediments, creating a complex channel structure. This group is highly active with a wide floodplain that actively recruits new cottonwoods and riparian vegetation. Shorelines are largely forested and relatively undeveloped in this group although vacation and full time homes, including a few large track conservation properties and resorts, do occupy the surrounding lands. Public access is highly developed via a trail network for both summer and winter access to the river.

UPPER OKANOGAN The Upper Okanogan group begins at the confluence of the Similkameen River with where lake Osoyoos outflows and forms the Okanogan at Oroville and runs south 15 miles, RM 76 - 61. The river meanders southward through a wide floodplain that narrows as it approaches Tonasket at RM 58. The confluence area is a low gradient, complex channel with multiple wide meanders, side channels, wetlands, point bars, and islands. This portion supports seasonal grazing, but is otherwise free flowing and dynamic. As the floodplain begins to narrow near RM 64, orchards and intensive agriculture begin to dominate the surrounding landscape. No developed or established public access exists within this 15 mile stretch.

UPPER SIMILKAMEEN The Upper Similkameen begins at the Canadian border in T40N R25E to RM 22.3 where it adjoins the Palmer Creek, the outflow of Palmer Lake. This portion of river supports a wide floodplain with a robust complex channel, marked by side channel wetlands, abandoned oxbows and lush riparian vegetation. Land uses are primarily grazing and interspersed agriculture. Access to the Upper Similkameen is available at two WDFW sites located at RM 23.6, and RM 26.2, respectively.

WALKER LAKE Walker Lake is located in Section 27 T38N R30E. The lake is 40 acres in area. The lake is nearly circular in shape and shallow with a maximum depth of 32 feet. The lake bottom is sandy clay and the shoreline is lined by a sandy beach around its entire perimeter. The western shoreline is forested whereas the eastern shoreline is open rangeland. The shoreline is privately owned with no public access.

WANNACUT LAKE Wannacut Lake lies with T39N R26N in Section 24. The lake sits in a north/south trough surrounded by moderately forested hills. The shoreline measures approximate 5 miles in length. The eastern shoreline has been heavily subdivided for residential/vacation cabins, while the western shoreline is still intact and supports open range lands. There is one public access site in SW corner of the lake with a boat ramp.

WEST OSOYOOS The West Osoyoos group is located in Section 22 T40N R27E. Lake Osoyoos measures 2055 acres and therefore constitutes a shoreline of statewide significance. There are extensive gravel and sand beaches along the shoreline. West Osoyoos constitutes its own group based on its high level of residential development including homes and docks. The entire lake is designated within the city of Oroville (and is served by public water and some sewer). Public access is found along the western shoreline at the City of Oroville Deep Bay with picnic, launch and swimming areas and numerous private campgrounds and small resorts that provide access.

WEST SANPOIL RIVER The West Fork of the Sanpoil River drains an area of nearly 200,000 acres. This portion of the Sanpoil runs in a SE direction from T36N, R30E to T35N, R31E for approximately 10 miles before it enters the mainstem of the Sanpoil. The surrounding landscape includes forested slopes and open rangelands. The West Fork of the Sanpoil sustains an actively floodplain with wide meanders that supports agriculture and grazing. Ownership includes private and Forest Service lands. No public access is documented.

WHITESTONE LAKE Whitestone Lake is located in Section 17 T38N R27E. The lake measures 147 acres. The lake is a natural, silt-bottomed lake but is supplemented by irrigation and detained by a small dam. The lake is used for recreation with several small resorts and irrigation storage. The northeastern shoreline has been stabilized for the Loomis-Oroville RD. A boat launch on State land provides access.

WINTHROP TOWN Shorelines in the Winthrop Town group include the Chewack River from about RM 0.5 downstream to the confluence with the Methow River, and the Methow River between RM 49-51. Where these rivers meet is a dynamic braided channel. Efforts to control channel movement have resulted in a flood control levee along the right bank of the Methow (which serves a ski trail in the winter) and extensive rip rap along the Chewack to protect riverfront businesses and two bridges. Nevertheless, this highly developed portion of the river still maintains a high level of ecological integrity and the Winthrop Park offers direct public access at the confluence for fishing, swimming and light boat craft launch. A pedestrian bridge at the north end of downtown provides access to a new park area along the Chewuch River and in south Winthrop, Heckendorn Park provides access to the Methow. Visual access to the river is an important feature to the town’s identity as the riverfront properties command high real estate values. Recreation and commercial interests are a top priority for shorelines in this group.

Okanogan Project

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Bureau of Reclamation
1996

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Okanogan Project

Isolated from markets, money and progress, but eager to join the rest of the irrigated West, Reclamation's Okanogan Project brought the twentieth century to north central Washington state. The persistence of some 200 irrigators along the Okanogan River directed engineers to a spot described by historian Alvin M. Josephy, Jr., as the "last outpost of frontier life" in the American West. In the years prior to Reclamation's arrival and the subsequent completion of a connecting railroad line, as fellow Washingtonians in Seattle and Spokane traveled paved streets in motor cars and trolleys, remote Okanogan still relied on stagecoaches and stern-wheeled riverboats coming up the Columbia River for supplies and contact with the outside world.

Logic should have led Reclamation toward the promising Yakima region southwest of Okanogan County as the first authorized project in Washington. However, residents of Okanogan County mastered bluster and perseverance and lobbied Reclamation to build in an area which could support only a few cash crops, and did not have a connecting railroad line to outside markets.

In the summer of 1910, Reclamation's engineers felt a sense of accomplishment after completing their first hydraulic-fill earth dam on the Okanogan Project. All the local irrigators could feel was anticipation, as their county would soon be blanketed with apple orchards bearing, in the words of one grower, "fruit prolific and luscious." Okanogan residents, tempted by a vision of prospective wealth dangling from the branches of their saplings, ignored the wisdom of the English poet Robert Browning: "Where the apple reddens/Never Pry/Lest we lose our Edens." Eden briefly came to Okanogan County, but overestimation, bad luck and the elements conspired to take the luster off the growers' hopes.

Project Location

Situated in one of the continental United States' most secluded regions, the population center and county seat, the town of Okanogan, is a little over 200 miles east of Seattle. Shielded behind the Okanogan, Wenatchee and Cascade Mountain ranges, the county is cut-off by these natural barriers from the east-west traffic routes crossing the state. Okanogan County is dotted with a series of broken mountain ranges descending into rolling valleys. Project boundaries are the Okanogan River to the East, a series of foothills on the West, the town of Okanogan on the Southwestern extremity, and the town of Riverside on the north edge. Within project lands, there are 20 miles of main canals and 43 miles of laterals to serve 5,038 irrigable acres along the Okanogan River.

The project lands rise from the Okanogan River on an eroded form of land known as benches. The benchlands extend back three miles from the riverbank to the foothills. The sandy, loose soil on the lower benchland along the river is called by locals as "The Flat." The dirt on the upper benches is a rich volcanic ash underlaid with gravel, and unlike the soil along the river, will grow several different crops. The summers are hot and sunny, and in some years, unforgiving. Annual precipitation of 11.8 inches, plus a growing season of 168 days from May to September, provides favorable conditions for raising apples. These elements in combination set the stage for a century-and-a-half of quiet drama.[1]

Historic Setting

For centuries, north central Washington was home to a myriad of tribes, including the Northern and Southern Okanogan. Before Anglo-European migration crossed their lands, the area's tribes were semi-nomadic, surviving by fishing and berry picking in the spring and summer and deer hunting in the fall. Relations among the regional bands were peaceful, as each tribe fought only to defend themselves from non-Okanogan attackers. In July 1811, whites made their first appearance in the Okanogan River Valley in search of beaver to satisfy the increasing demand for pelts. The "Oakinackken" (one of 50 early spellings of the tribe's name and pronounced Oh-kaw-nogan) co-existed with the wandering newcomers until the late 1840s when the fur trade had gone out of fashion. A small gold find at Fraser River in British Columbia

1. U.S., Department of Interior, United States Reclamation Service, *Third Annual Report on the Operation and Maintenance of Reclamation Projects* (Washington, D.C.: Government Printing Office, 1912), 154; William E. Warne, "Land Speculation," in *Reclamation Era*, August 1947, 179; U.S., Department of Interior, Water and Power Resources Service, *Project Data*, (Denver: United States Government Printing Office, 1981), 719.

lured a few individuals to pass through the county along the Cariboo Trail. In 1886, another rush of gold seekers roamed through the county, but most of those fortune hunters left when the rush petered out, as homesteading was not in their characters.[2]

Presumed to be the first white settler, Hiram Francis "Okanogan" Smith, settled near Lake Osoyoos along the Canadian border. Besides his mining and ranching interests, Smith is remembered for planting the first apple trees in the area. In the winter of 1861, Smith transported 1,200 young apple trees to his ranch. Smith also dug the region's first irrigation ditch to water his young orchard. By the end of the 1860s, 24 acres of apples and eight acres of peaches, pears and grapes were growing on his property.

Throughout the 1860s and 1870s, Smith, and the area's sole saloon keeper, John Utz, appear to be the only white settlers in what later became Okanogan County. In the early 1870s, to encourage white settlement, the Federal government confined 4,200 Indians to a reservation running east from the Columbia River to the Pend Oreille River and from the U.S-Canadian border south to the Spokane River. Expressing the newcomers' viewpoint were men like Thomas H. Brentz, delegate to Congress from Washington Territory, who justified the government's reduction of the reservation saying: "There is so much wealth here and so few Indians to use it." However, into the 1880s, the region remained sparsely populated as one new arrival from the East described the county holding "only 30 white men and three white women in an area larger than Massachusetts." Over the next 15 years, in a confusing series of shifts, government agencies rearranged the borders of the reservation. In 1886, the lands west of the Okanogan River were detached from the Colville Indian Reservation and advertised in the East for settlement. The numerous Eastern Washington tribes had the option to obtain allotments to farm west of the Okanogan River or move to the Colville reservation on the river's east bank.[3]

West of the river, between 1886 and 1888, Dr. Joseph I. Pogue, and a horticulturalist, H.C. Richardson, dug four miles of ditch to deliver water from Salmon Creek to three different

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2. Bruce A. Wilson, *Late Frontier: A History of Okanogan County*, (Okanogan County Historical Society: Okanogan, Wash., 1990), 17, 38. In the language of the Southern Okanogan, the name for their tribe was "Sinkaietk."
3. Wilson, *Late Frontier*, 70-7, 200; *Project Data*, 720.

ranches. The duo fancied themselves potential fruit producers and realized that a little over 11 inches of rainfall a year made irrigation necessary for their nursery stock. As of 1893, Pogue's fruit trees covered 60 acres, and the orchard was successful enough to encourage a small ripple of settlers to consider raising apples. An interested few came and planted forage crops for winter stock feed.

In an attempt to foster interest in irrigation, an Okanogan newspaper editor, S.T. Sterling, began to promote an elaborate irrigation system storing Salmon Creek water in two local lakes (Green and Brown) then transporting it by ditches and flumes to apple orchards north of the town of Omak. In 1897, an increasing demand for water from Salmon Creek sparked the creation of the Conconully Reservoir Company. The company managed the storage of almost 1,500 acre-feet of water in Salmon Lake. Other associations and individuals also began to dig. By 1908, fifteen ditches irrigated 1,423 acres along Salmon Creek and neighboring Spring Coulee and Pogue Flat.[4]

In 1902, the news reached north central Washington that President Theodore Roosevelt approved the Newlands Act. The birth of the Reclamation Service inspired Sterling to craft a slight exaggeration on behalf of his neighbors. In a letter to the newly formed U.S.R.S., Sterling stated "50,000 to 75,000 acres of arid land" along the Okanogan River was waiting to be reclaimed by an "inexpensive reservoir." Attached to the letter was a petition signed by 200 residents calling themselves the Okanogan County Improvement Club, also requesting the new Reclamation Service to come out and survey the land. That invitation opened the last frontier in the West to domestication.[5]

Project Authorization

On March 3, 1903, Chief Engineer of the Reclamation Service Frederick H. Newell, directed Seattle engineer T. A. Noble to go to Okanogan and research the feasibility of beginning the project. Noble completed his report in April 1903, and concluded Reclamation should begin

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4. Wilson, *Late Frontier*, 69, 220; *Project Data*, 720.
5. U.S., Department of Interior, Bureau of Reclamation, *Project Histories, Okanogan, Vol. 1*, (Washington, D.C.: Government Printing Office, 1910), 1-5.

a project utilizing the waters of Salmon Creek and nearby Johnson Creek combining a storage facility constructed at one of five potential sites. Those sites were Conconully and Salmon Lakes, the Scotch Coulee, and Green and Brown Lakes. Throughout 1903-04, Charles E. Hewitt surveyed the entire county for the ideal damsite. Hewitt's report of October 23, 1904, to Noble, and Supervising Engineer H. N. Savage, recommended canceling the project. Hewitt believed the drawbacks of dam building on Salmon Creek included a prohibitive estimated construction cost of $45 per acre and inflated shipping rates for materials. Each of the five proposed was 50 miles from a rail line and accessible by boat for only three months out of the year.[6]

This setback swung the persistent settlers back into action. They sought the support of Congressman Wesley L. Jones of Yakima, who helped draft the Newlands Act of 1902. Local representatives went to Washington, D.C. to meet with Secretary of Interior Ethan A. Hitchcock to convince him to reconsider Reclamation's decision. Their arguments swayed Hitchcock, and he launched another round of investigations and reports. The revised plan proposed "the storage of 12,000 acre-feet of water in Conconully Reservoir and 4,300 acre-feet in Salmon Lake Reservoir; the water from Conconully Reservoir to follow the channel of Salmon Creek to a diversion point some three miles above the town of Okanogan."[7]

On December 2, 1905, Hitchcock authorized expenditure of up to $500,000 to build the Okanogan project. The cost of the plan included construction of the dam, necessary buildings, telephone lines, purchase of water rights, and a maintenance contract for 10 years. Assessment against 8,645 acres covered by the project would be $420,179, at a cost per acre of $48.60. The Okanogan Water Users Association, representing some 10,000 acres along the Okanogan River, formed immediately following Hitchcock's decision.[8]

If patience and determination are necessary in raising apples, those same qualities came in handy in the growers' campaign to convince Reclamation to trek out to Okanogan County and

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6. *Project Histories, Okanogan, Vol. 1,* 1-5; *Third Annual Report on the Operation and Maintenance of Reclamation Projects*, 153.
7. Wilson, *Late Frontier*, 221; U.S., Department of Interior, Bureau of Reclamation, *Project Histories, Okanogan, 1959,* (Washington, D.C.: Government Printing Office, 1959), 1.
8. *Project Histories, Okanogan, 1959,* 2; Wilson, *Late Frontier*, 221.

raise Washington state's first federally built dam. From an engineering and commercial viewpoint, a better location to build would have been the Yakima Valley some 190 miles southwest of Okanogan, where the railroads and population were both thriving. Still, in keeping with Reclamation's quest to reclaim all the arid West, Okanogan's growers were given a second hearing. Their persistence won them the authorization race with their larger neighbor, as Hitchcock sanctioned Yakima ten days after Okanogan, on Dec. 12, 1905.

Construction History

In early April 1906, construction began on the worker's camp, located at the foot of Pogue Mountain on vacant public land. The camp was near the proposed main canal and laterals and a spring on Pogue property. Entirely comprised of wood framed structures, the camp consisted of a project engineer's house, office building, bunkhouse, stable and a mess house measuring 18 by 60 feet. All construction from campsite to dam was completed by "force account" through small contracts with local contractors. Project engineers made the decision to use force account labor after they felt bids to construct a storage works and main canal were too high.[9]

By mid-April, 7,206 acres of Okanogan County were designated as project lands. Nearly all the pre-existing water rights and ditches now belonged to the project. Work at the dam site began in mid-August 1906, with the clearing of 460 acres of partly wooded meadow by contract labor to prepare the land for the main canal and laterals. Later in 1906, the first element of the Okanogan Project, the Salmon Creek Diversion Dam, was finished 12 miles downstream from the proposed Conconully Dam. The diversion dam is six feet high and 140 feet across at the crest. The dam diverts the Salmon Creek releases to the Main Canal, which is two miles long and has a capacity of 100 cfs. This canal divides at a "Y" into the Six mile long High Line and the four mile long Low Line Canals. Salmon Creek has a 300-cubic-foot-per-second overflow capacity.[10]

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9. *Project Histories, Okanogan, 1910, Vol. 1*, 24-7.
10. George Wharton James, *Reclaiming the Arid West: The Story of the United States Reclamation Service*, (New York: Dodd, Mead and Company, 1917), 328-9; U.S., Department of Interior, Bureau of Reclamation, *Annual* (continued...)

Preparatory work on the Conconully Dam commenced in March 1907. The dam's design featured a core wall of sheet piling covered with rock and earth next to a spillway and an outlet tunnel. In the middle of May, excavation revealed the foundation's soil was too loose to support an 80-foot high earth dam. Construction halted and a new round of surveys began farther up the canyon in search of a better location. On June 8, the Project Engineer, Christian Andersen, and a three man Board of Engineers approved moving the dam to a new site 3,000 feet north of the original excavation. The new location reduced the dam's storage capacity from 16,000 to 13,000 acre feet, but relocation was necessary for the project's longterm stability.[11]

Conconully Dam was the first project in Reclamation's short history to be built by hydraulic methods. Construction Engineer Lars Bergsvik previously worked in hydraulic mining before he oversaw the Okanogan Project. His expertise would guide other engineers and laborers since Reclamation lacked standard plans of their own to follow. The granite and soil of nearby Peacock Mountain provided the dam's material. A little more than a thousand feet west of the dam, two rock pits alongside the mountain were cleared with the help of blasting powder. The pits were used alternately; one a starting point for sluicing rock and earth to the damsite, and the other a holding area for rocks too large to be carried by water down a steel-lined flume. A team of workmen broke the larger rocks with sledgehammers before the material went down the flume.[12]

Darting over hills and around trees for almost three-and-a-half miles, the flume carried water from the North and West Forks of Salmon Creek to gravel pits on Peacock Mountain south of the town of Conconully. The fast moving water sluiced 349,455 cubic yards of dirt and rock from the pits through 3,000 feet of flume to the damsite. Ninety-six foot high trestles, resembling a towering spider web or an amusement park roller coaster, supported the flume. The flume construction proceeded in three stages during 1907, 1908 and 1910. The finished structure

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10. (...continued)
Project History, Okanogan Project, Vol 30, 1984-5, iii.

11. U.S., Department of Interior, United States Reclamation Service, *Project Histories, Okanogan, Vol. 3*, (Washington, D.C.: Government Printing Office, 1912), 35-9.

12. Herbert A. Yates, *A Pioneer Project*, (Portland, Ore.: Metropolitan Press, 1968), 29-30.

followed a sloping downhill grade of four to three percent. The man-made channels carried 25 cubic feet per second (cfs) of water, and the largest rocks carried down the four percent grade flumes weighed about 250 pounds. At the end of their ride at the damsite, a shower of rock, dirt and water tumbled from the flumes to form the embankment.

At the damsite, side gates swung across the flume every 16 feet, discharging the entire flow of water and material. Two gates near the dam opened simultaneously (according to the amount of water carried by the supply flume) usually turning out at the first opening or gate, releasing coarse material on the outside slopes to form a levee. The other two gates discharged on the inside, carrying finer material toward the center of the dam, manufacturing a pond between the two levees. In 1909, engineers ordered the placement of a puddle core to compensate for the lack of fine material at the rock pits. Conconully Dam's puddle core is a water-tight core made of silt and very fine sand stratified in thin layers. Much of the silt and sand was dredged from the bottom of Salmon Creek.[13]

As a transfusion of earth formed the dam above ground, workmen below were drilling 394 feet through a hill on the east end of the works sculpting a tunnel. Hand drills were used on the seamy granite to create a tunnel for irrigation flow. Excavation began in July 1907 and concluded six months later. For the next three years, the previously perpetual tranquility of Okanogan County was disturbed by the sounds of blasting powder smashing rock and the running jumble of earth and rock shooting down the flumes.[14]

In the second year of construction, 1908, the wear and tear of thousands of cubic yards of dirt and rock coursing through the main flume was noticeable. Five times during the first season the No. 10 mild steel plates had to be replaced after taking a beating from the rocks. Eventually, the flume was redesigned so the wear was redistributed more evenly. The seasons annually hindered construction, as the cold and snowy winters halted sluicing, and lack of precipitation in

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13. U.S., Department of Interior, Bureau of Reclamation, *Geologic Report for Modification Decision Analysis, Safety of Dams Program, Conconully Dam, Okanogan Project, Washington*, (Boise, Id.: Pacific Northwest Region), 1992, 1; *Final Report on the Construction of the Conconully Hydraulic-Fill Dam*, 33.

14. U.S., Department of Interior, United States Reclamation Service, *Final Report On the Construction of the Conconully Hydraulic-Fill Dam, 1907-1910*, (Conconully, Washington: Reclamation Service, 1910), 8-24. The author of the final report was Construction Engineer Lars Bergsvik.

summer saw little flow to move material quickly through the flumes.[15]

Riding along the trestles across several ravines and draws, the silt, sand and rock pile eventually grew into a dam crest 1,025 feet long. After workmen dressed the slopes of the dam into neat lines, the finished structure stood 70 feet high. Work concluded in late June-early July of 1910. Between 1907 and 1910, the dam's diversion weir, main canals and laterals were also completed.[16]

Work on all projects progressed steadily except for two interruptions. On the night of January 27-28, 1907, camp headquarters caught fire and destroyed the assistant's quarters and many office files, maps, profiles and vouchers. The fire burned plans for a distribution system that resulted in month's delay while the plans were re-drawn.

In late July 1909, laborers and pitmen called the first general strike in Okanogan County history. In an average construction season, a shift employed 17 men clearing the pit and tending the flumes. Pay for these men ranged from $2.25 to $2.75 for an 8-hour day. Strikers demanded an increase of 50 cents a day and cookies once a week. The three day strike ended when the workers settled for a 25-cent pay raise. Management acceded to labor's demand on the cookies bargaining point.[17]

Despite the setbacks, on May 4, 1909, the first irrigation water flowed to 2,000 acres in the southern part of the project. As operations wound down in June-July, 1910, the finished product stood 70 feet high and contained 359,000 cubic yards of fill. Construction was also way over the original estimate of $500,000, as the project's remoteness and demanding climate pushed the final cost up to $1,513,287.[18]

In many areas, once Reclamation completed a reservoir, benefits could be seen almost immediately in nearby irrigated fields. Okanogan's apple producers practiced patience, as they grew potatoes, onion and beans between their rows of saplings. Growers faced a wait of up to

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15. *Final Report on the Construction of the Hydraulic-Fill Dam*, 25, 32; Yates, *A Pioneer Project*, 31.
16. Wilson, *Late Frontier*, 222.
17. *Final Report on the Construction of the Conconully Hydraulic-Fill Dam*, 43; Wilson, *Late Frontier*, 222; *Okanogan Record*, 30 July 1909, p.1. The *Okanogan Record* was printed in the town of Conconully. Articles from the *Record* are available from the Okanogan County Historical Society located in the town of Okanogan.
18. *Project Data*, 719, 721; *Annual Project History, Okanogan Project*, Vol. 1, 89.

seven years before their apple trees would bear fruit. In the intervening time, the partnership between local growers and Reclamation would remain close.

Post-Construction History

The Okanogan project saw a number of improvements in a 30 year period following completion of Conconully Dam. The first expansion was the construction of an electrical power and pumping plant completed in 1914. The building of nearby Salmon Lake Dam started in 1919 and completed in October 1921. As Salmon Lake was under construction, North Fork Salmon Creek Diversion was completed in 1920.

These improvements increased Conconully Reservoir's capacity and responded to changes in the region's climate. In 1911, although only 65 percent of the project's acreage was under cultivation, the water supply was exhausted by August 1. The quantity of water delivered to the 5,038 acres in cultivation averaged about 1.38 acre feet per acre. Engineers blamed the shortage of moisture on seepage from the Project's three canals, High Line, Low Line and Main. The three channels went into service in 1917, and their immediate leaking was an unwelcome headache in an area growing drier each summer. Between 1912 and 1917, to reduce precious moisture losses, much of the distribution system was lined with concrete. Reclamation repeated the procedure in the spring of 1922. The distribution system included approximately 25 miles of laterals, many of which are closed metal or concrete pipes. As an additional resource fighting back against the increasingly arid summers, a pumping plant was built at Duck Lake, some ten miles from Conconully Dam. The pumping plant lifts water from Johnson Creek and the High Line Canal into Duck Lake for pumping in the canals.[19]

The difficulty of raising apples on sandy soil was evident by the end of the 1910s. In 1919, Reclamation began to reduce acreage served by the project by purchasing owner equity and canceling water rights on sandy land properties. When the Okanogan Irrigation District took over management of the project on January 1, 1929, water rights had been cut from a high of

19. U.S., Department of Interior, United States Reclamation Service, *Project Histories, Okanogan, Vol. XI, 1922*, (Washington, D.C.: Government Printing Office, 1922), 113-4; *Project Data*, 720; U.S., Department of Interior, Bureau of Reclamation, *Modification of Conconully and Salmon Lake Dams*, (Denver: Office of Chief Engineer, 1967), 26.

10,999 acres to 7,300 acres. Reduction continued in the following decades, until the remaining district controlled land totaled 3,700 acres by the late 1940s.[20]

The construction of the new Salmon Lake Dam, a mile northeast of Conconully Dam, began in 1919. Average wage for Salmon Lake laborers was $3.60 a day. Salmon Lake's construction design and techniques were similar to Conconully's. Like its older neighbor, Salmon Lake is an earthfill structure standing 42 feet high. Two feet of riprap protects the upstream face of the dam. The siphon spillway and outlet works combine into a single structure located on the dam's left abutment. Salmon Lake's adjoining reservoir, Conconully Lake, holds 10,500 acre-feet of water. A small diversion headworks structure on Salmon Creek diverts the flow into Conconully Lake through a short feeder canal. Work on Salmon Lake Dam concluded in 1921.[21]

During the creation of Salmon Lake Dam, Reclamation attempted to strengthen Conconully Dam from excessive seepage. In the early 1920s, workers drilled down to the puddle core and implanted an 8-inch by 10-foot concrete parapet wall into the dam's foundation. The height of the dam also increased by 2.5 feet by the addition of gravel topping. These improvements did not last long, as on June 1, 1938, the discovery of a sink hole at the foot of the parapet wall on the upstream side of Conconully Dam, meant more rehabilitation. A contemporary study showed two feet of the puddle core eroded under the wall. The inside of the dam was filled with puddled silt and no additional faults were uncovered. Reclamation's Denver office blamed the problem on faulty upgrading done in the 1920s. More erosion four years later required an additional 2,800 cubic yards of clay material backfilled into the puddle core. During the 1930s, the Works Progress Administration (WPA), planned to increase Conconully's storage capacity, but constant repair work delayed those intentions. In 1948, a major rainstorm beginning May 27 and continuing through the 29th, pushed the county reservoirs past their capacities. Over 71,000 acre-feet destroyed the North Fork Salmon Creek Diversion, but it was rebuilt later

20. *Annual Project History, Okanogan Project*, 1959, 2.
21. *Project Histories, Okanogan, 1959*, 5, 47; *Modification of Conconully and Salmon Lake Dams*, 15.

that year.[22]

The 1950s and 1960s saw a period of upgrades and refinements. In 1951, a contract for rehabilitation of Conconully Dam between Reclamation and the district was drawn up. The funding for the new canal linings and over 100,000 linear feet of pipe lines came from the project's operations and maintenance budget. The late 1960s saw more changes made in Conconully's facade. In 1966, the project replaced the intake structure and the lined upstream tunnel. In 1967, a rare reservoir spill exposed a serious weakness in Conconully Dam's concrete structure. During 1968-69, repairs on the crest of the dam were accomplished with new embankment materials and a riprap. The deteriorating concrete spillway was replaced with a concrete-baffled apron design with a capacity of 11,580 cubic feet per second.[23]

The most recent addition to the project is the Shell Rock Point Pumping Plant on the Okanogan River. Completed in 1979, the plant pumps water from the Okanogan River to the High Line Canal during water short years. Shell Rock has four pumps, each with a capacity of 8.3 cubic feet per second discharging flow into the High Line Canal.[24]

Eighty years after its original construction, the Okanogan project evokes memories of how irrigation captured the imagination of Western landowners. Since its beginnings, nature provided a few reminders for engineers and growers of who was truly in charge of their destinies.

Settlement of the Project

The Newlands Act established the Reclamation Service, and under the measure, no landowner serviced by a government water project would be supplied with irrigation water for more than 40 acres. Those who claimed squatters' rights on 160-acre homesteads dating before the turn of the century, began to sell off three of their four 40 acre tracts to new buyers. Newcomers made homes and planted orchards in Pogue Flat, the "sand flats" north of Omak, and a location called the "Cherokee Strip," named in honor of the Oklahoma land rush spot. The

22. *Modification of Conconully and Salmon Lake Dams*, 3, 26; Yates, *A Pioneer Project*, 90.
23. *Geologic Report for Modification Decision Analysis*, 3-4.
24. *Geologic Report for Modification Decision Analysis*, 3-4; *Project Data*, 719.

strip's 1,100 acres of stubborn sandy loam needed cover crops like clover hay and alfalfa to make the land fertile and retentive of moisture so trees could be planted. This Cherokee Strip extended west of the Okanogan River from Omak to Riverside nearly 10 miles to the north. The years between the completion of the Conconully Dam and large scale production were tough ones for growers. Many homes were mortgaged and their owners were living "not in a very prosperous condition."[25]

A branch of Okanogan County's agricultural strategy depended on the completion of the Reclamation project. The other relied on the arrival of the railway to link the region to national and world markets. Before 1913, farmers could haul produce by wagon to the neighboring towns, or go to the community of Brewster 25 miles away, to ship by sternwheeler steamboat at headwaters of the Columbia River. In 1910, the Great Northern Railroad graded and built a branch line along the Okanogan and Columbia rivers from Pateros in the south to Oroville in the northern end of the county. The line connected Okanogan's groves to the markets of Spokane and Vancouver, British Columbia. By 1914, the growers shipped 20 carloads by the Great Northern Railroad. A year later, two hundred cars shipped the first large crop from Omak and an additional hundred cars from Okanogan. The initial shipment showcased apples, but also included apricots and peaches. Iced refrigerator cars rushed fruit from the orchards to Chicago and New York City. At market, the average price growers received for their fruits was a $1 per box.[26]

Okanogan irrigators reacted much like other project farmers across the West after Reclamation completed a job. They were awash in a river of hyperbole contemplating the promise of their futures. On November 20, 1909, apple grower Albert Rogers wrote to Okanogan Project Operations Manager Ferdinand Bonstedt, that with open access to the Pacific Ocean, Okanogan apples should "enter the homes of the poor both in our own nation and in Europe." Post construction prospects were so bright, grower C. H. Knosher wrote, "five acres of

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25. U.S., Department of Interior, United States Reclamation Service, *Project Histories, Okanogan, Vol. 5, 1915*, (Washington, D.C.: Government Printing Office, 1915), 61; Yates, *A Pioneer Project*, 48.
26. Wilson, *Late Frontier*, 222.

fruit will keep an ordinary sized family in comfort and independence; ten acres will afford luxuries; twenty acres will accumulate earthly goods almost fabulous of conception."[27]

A Reclamation statistician returned the bouquets, as he described those living on the project as "cosmopolitan, of high intelligence, and strongly attached to their homes." Average tracts of ranchland for these gentlemen farmers and their families ranged from five to 30 acres. Project water irrigated 448 farms in the first decade after the dam's completion.[28]

In 1906, before construction, unimproved land went for $10 an acre. By 1913, the same land sold for $250 to $300 an acre. Undeveloped land in the Cherokee Strip and Flats area was selling for $75 an acre after Conconully Dam. An acre of land planted with three to four year-old orchards sold for $400 to $525. One grower, C. C. Parkman, recommended other farmers in the West follow the Okanogan example, "Looking backward, the guideboards along the trail I have traveled read; Get a homestead if you are *sure* that Uncle Sam will water it, but be *sure*."[29]

Nineteen-sixteen was a pivotal year in the history of the Okanogan Project. It signaled the last of the good times and pointed toward upcoming decades of struggle. That year, a reclamation statistician, C. J. Blanchard, reported that in the Okanogan Valley it had been 20 years without a killing frost. The 7,850 acres in production that growing season was the most acreage irrigated in the history of the project. In the immediate years after Conconully's completion, the winters were mild with average snowfall and the summers were warm. The perceived predictability of the seasons caused one Reclamation staffer to comment, "the uncertainties in fruit growing which have made the industry so much of a gamble in other parts" did not bedevil Okanogan County. In the mid-1910s, the county's three main towns, Okanogan, Omak and Riverside, with populations of 800, 400 and 500 respectively, began to benefit because of the developing agricultural activity. It seemed Okanogan's orchards were heralding the promised Eden, but soon conditions would turn the promise into a broken vow.[30]

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27. U.S., Department of Interior, United States Reclamation Service, *Project Histories, Okanogan, Vol. 3, 1912*, (Washington, D.C.: Government Printing Office, 1912), Box 121.
28. C. J. Blanchard, "Okanogan Project, Washington," in *Reclamation Record*, November, 1916, 516.
29. Warne, "Land Speculation," 179; *Project Histories, Okanogan, Vol. 3, 1912*, Box 121.
30. Blanchard, "Okanogan Project, Washington," 516.

A grower, Fred McMillan, summed up Okanogan's thirty year nightmare: "The years 1912, 1913 and 1914 and were good ones for farmers. From 1915 on, it was a different world. . . the beginning of the dry years which lasted into the 1940's. The morning sun came up hot and stayed hot. Clouds raised hopes, then faded away. Ponds and lakes dried up. . . The crops were too stunted to harvest."[31]

In 1920, five years into the drought, Reclamation constructed two pumping stations to increase water on the project, and private and federal agencies dug wells. No runoff from winter snowpack and a succession of dry years demanded the creation of pumping plants at Robinson Flat, Duck Lake and Salmon Lake. Despite a succession of dry years, 1922 still holds the record for the largest amount of apples grown on the project in a year. The total year was 1.2 million boxes with an estimated return of $1,537,149. It would be the last happy news for a while.[32]

In November, 1928, the $1.5 million debt owed to the Federal government by the Okanogan Irrigation District was scaled down to $310,000 payment at the rate of $10,000 a year over a period of 31 years. Reclamation worked with growers and the District between 1917 and 1928. In those eleven years, the district spent almost $2 million of its own money to purchase water outside of the project to compensate for the drought.[33]

The project had collected 50,421 acre feet of runoff in 1916. Two years later, that amount fell to 8,860 acre feet. The water shortage hit its most critical level in the early days of the Great Depression, as the Conconully reservoir clung to only 1,142 acre feet in 1931. Tree stumps in the bottom of the lake left from construction thirty years earlier now cooked under the hot sun. Abandoned farms and families packing up became a familiar sight as sand storms blew across the orchards and the county's small towns.[34]

In the 1920s and early 30's, two-thirds of the orchards were mortgaged. One resident whose family had paid $2,500 for an orchard in the sand flats told of a ditch rider guiding their

31. Wilson, *Late Frontier*, 251.
32. U.S., Department of Interior, United States Reclamation Service, *Project Histories, Okanogan, Vol. XI, 1922*, (Washington, D.C.: Government Printing Office, 1922), 37.
33. *Project Histories, Okanogan, 1959*, 2.
34. Yates, *A Pioneer Project*, 98, 121-2.

allocation of water into their box: "The water did not go more than 10 feet from the box before disappearing into sand. We abandoned the place, and our $2,500, after three months."[35]

Excessive rainfall in 1936 and 1948 offered relief from the never ending dust and dryness, but by the 1940s, the hopes that had fired the imaginations of the first generation of growers were long gone. Through Reclamation's buy-outs and growers' abandonment, the original 10,099 acre project stood at 5,038. In a Nov. 2, 1942, Okanogan Project Manager N. D. Thorp wrote to Reclamation Commissioner John C. Page, after years of drought and recent wartime inflation that many growers were "in a turmoil of bewilderment," over their situation. He added even successful growers were considering abandoning their orchards, if additional financial hardships awaited them.

Herbert A. Yates, Reclamation's chief clerk and fiscal agent during the Okanogan project, commended growers efforts. In 1968, Yates wrote in his memoir if some considered the project a "failure," judging by abandoned farms and reduced acreage, it was "due solely to the insufficient water supply." Visiting Reclamation officials shared Yates' opinion, as they were "often in praise of the farmers who still fought on, even after they were licked."[36]

Over the course of the next fifty years, the Okanogan project remained isolated. As late as 1954, the U.S. Department of Commerce ranked the project fifth in the nation with 626,677 apple trees. Irrigated acreage today is half in orchard, half in pasture and alfalfa hay. The county's population still is sparse compared to the rest of the state. In the 1990 census, the state of Washington had 4.8 million residents. In the same census, the population of Okanogan County was 33,350 with the town of Okanogan numbering 2,370 citizens.[37]

Uses of Project Water

Before Reclamation's arrival, pioneer apple growers would haul water in buckets from springs and wells to soak young trees individually. Orchards need to be irrigated in any six-

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35. Wilson, *Late Frontier*, 223.
36. Yates, *A Pioneer Project*, 78.
37. U.S. Department of Interior, Bureau of Reclamation, *Office of the Chief Engineer, General Correspondence Files, 1902-42*, Box 998, File 234-C; U.S., Department of Commerce, Bureau of the Census, *1990 Census of Population and Housing, Pacific Division, Vol. 1*, (Washington, D.C.: 1991), Summary Tape File 1A; Yates, *A Pioneer Project*, 106. In 1954, leading the apple tree census was Yakima County, Washington with 1,495,426 trees.

week period during the summer or the trees will die. Replacement orchards require six years to begin production and ten years to reach full growth. After Reclamation completed the project, settlers tried a colorful variety of apple plantings. Settlers experimented with Winesaps and Johnathans, before moving on to Spitzenbergs, Rome Beauties, Arkansas Blacks, Yellow Newtons, Ben Davis and King Davids, and Winter Bananas in an attempt to decide which kind thrived in the Okanogan soil. The two varieties currently dominating production are Red and Golden Delicious. In the late 1910s into the 1920s, much of the crop went east, but since then more Okanogan apples ship in greater numbers to the southern United States and California.[38]

In 1943, the project serviced 397 farms. In 1990, the number shrank to 74 full time and 169 part time farms. At the beginning of the 1990s, 2,289 acres of apples were in production out of a total of 5,038. Total dollar amount of apple production was $3,845,520, yielding for growers an average of $8.00 per acre. The amount of all fruit grown (apples, peaches, pears and cherries) came to $5.4 million. Growers still harvest alfalfa and other forage crops for livestock. Okanogan's yields are not as colossal as their neighbors in the Yakima or Chief Joseph projects. In 1990, Yakima grew $227.6 million worth of apples on a little over 59,000 acres and Chief Joseph raised $87.6 million on 22,055 acres.[39]

Conclusion

The growers' hopes of transforming acres of Okanogan County into the nation's apple orchard were as porous as the lower benchland along the Okanogan River. Separate goals drove growers and Reclamation to attempt this gamble. For Reclamation, it was an opportunity to try out new methods of dam design and construction, and for the most part, they succeeded. For the growers, it was a chance to build a fortune, and unfortunately, all who tried were not successful. The aspirations of these two groups produced a situation full of contradictions: a capitalist Eden provided by federal money and technology centering on the production of the most romantic of nature's gifts -- the apple. If the project's design ignored the longterm moisture-gathering

38. Wilson, *Late Frontier*, 222; *Modification of Conconully and Salmon Lake Dams*, 26.
39. U.S., Department of Interior, Bureau of Reclamation, *Crop Report and Related Data; Federal Reclamation Projects*, (Denver: 1943), 28; U.S., Department of Interior, Bureau of Reclamation, *1990 Summary Statistics: Water, Land and Related Data*, (Denver: 1991), 153.

capacity of the watershed and was unsuspecting of the damage a multi-year drought could do, it still was a worthy effort. A monument to those who tried can be found in Northern Okanogan County near the Canadian border. Almost a century and a half after saplings were first placed into Okanogan soil, five bent and gnarled fruit trees planted by Okanogan Smith are still producing.

About the Author

Robert Autobee holds a Masters degree in History from the University of Northern Colorado. The Colorado Historical Society published his thesis, *If You Stick With Barnum: A History of a Denver Neighborhood*, as part of their *Essays and Monographs in Colorado History* series in 1993. He has worked as a reporter for several different Colorado newspapers, and for a national environmental newsletter, *Western Resources Wrap-Up*, based in Washington, D.C.

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