DRAFT WRITTEN FINDINGS OF THE
WASHINGTON STATE NOXIOUS WEED CONTROL BOARD
Based on the updated *Myriophyllum spicatum*, Eurasian watermilfoil, written findings
Proposed Class C noxious weed for 2018

Scientific Name: *Myriophyllum spicatum* L. x *Myriophyllum sibiricum* Kom.

Common Name: Hybrid watermilfoil; Eurasian watermilfoil hybrid

Synonyms: For hybrid: none; for *Myriophyllum spicatum*: none; for *Myriophyllum sibiricum*: *Myriophyllum exalbescens* Fernald; *Myriophyllum spicatum* L. var. *exalbescens* (Fernald) Jeps.

Family: Haloragaceae

Legal Status: Proposed Class C noxious weed; *Myriophyllum spicatum* Class B noxious weed

Additional Listing: *Myriophyllum spicatum* is on the Washington State quarantine list (WAC 16-752)

Image: Hybrid watermilfoil stem, stem cross-section, and leaf, sample from Mattoon Lake in Kittitas County. Image by Jenifer Parsons, Washington State Department of Ecology.

Description and Variation:

Hybrids of Eurasian watermilfoil and northern watermilfoil are increasingly common in Washington State and are now being considered for listing as a Class C noxious weed.

These hybrid watermilfoils have intermediate characteristics, including a variable number of leaflets, usually in a range of overlap between the parent species, and some genetic strains may form turions, while others will not (R. Thum, personal communication, 2015). Hybridization occurs frequently, and therefore the hybrids have variable characteristics relative to their parents. Also, second generation hybrids have been found, where the hybrid back-crossed with one of the parents, leading to additional physical traits and potential complications where management is concerned (Zuellig and Thum 2012). Genetic analysis is required to be certain of the species when hybridization is suspected (Moody and Les 2002).

Eurasian watermilfoil, northern watermilfoil, and hybrid watermilfoil, are submersed perennials with feather-like submersed leaves and flower stems with small flowers and very small leaf-like bracts that typically rise above the water surface. While identification between the two parent species is challenging, it may be possible by looking at morphological characteristics. Northern watermilfoil can be distinguished from Eurasian watermilfoil by the number of leaflets (less than 24 per leaf) and a more triangular overall leaf shape, with the leaflets often perpendicular to the central axis. However, these traits can be variable, and plants with close to 24 leaflets are especially tricky. Early season leaf growth and leaves on floating fragments of Eurasian watermilfoil often resemble northern watermilfoil. In the late summer and fall, northern watermilfoil will form turions (overwintering buds) at the stem tips that look like short segments of dark, densely crowded leaves (Eurasian watermilfoil does not form turions). Identification of hybrid watermilfoil requires morphological and genetic analysis due to its intermediate characteristics (Moody and Les 2007). See Table 1 for a summary of plant characteristics that also includes whorled watermilfoil, *Myriophyllum verticillatum*, another native watermilfoil species in Washington.

Unless otherwise noted, descriptions below are from Scribailo and Alix (2014), and Ceska and Ceska (1999).

Roots: <u>Both species and hybrid</u>: fibrous, with slender, short rhizomes. Also forms adventitious roots at leaf nodes, especially on fragments. Rhizomes (sometimes considered stolons) are important in vegetative reproduction (Madsen and Smith 1997).

Stems: <u>Both species and hybrid</u>: terete (round in cross-section), glabrous (without hairs) from pale greenish-tan to red in color, up to 6 meters long (though length is not confirmed for hybrid).
<u>Eurasian watermilfoil</u>: stems often highly branched at or near the water surface (DiTomaso and Healy 2003).
<u>Northern watermilfoil</u>: stems branch lower in the water column and not as profusely as Eurasian watermilfoil.

Image: left, two hybrid watermilfoil stems on the left and one northern watermilfoil stem on the right, plants from Loon Lake, Stevens County; right, close up of hybrid watermilfoil leaves. Images by Jenifer Parsons, Washington State Department of Ecology.

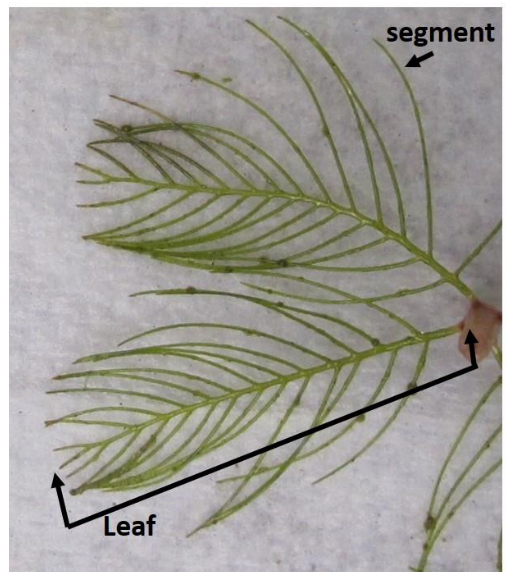


Image: Two hybrid watermilfoil leaves growing from cut stem, image by Jenifer Parsons, Washington State Department of Ecology.

Leaves: Both species and hybrid: All with two types of leaves, feather-like submersed leaves and very small leaf-like bracts on the flower stem that typically rise above the water surface.
Eurasian watermilfoil: Usually grow in whorls of 4, though occasionally 3 to 5. Either sessile or on very short petioles (to 0.4 mm). Submersed leaves are feather-like (pectinate), wider in outline toward the middle and tip than at the base (obovate), typically 18 to 32 (14-36) mm long by 10-20 (to 30) mm wide, and with a blunt to rounded tip. There are generally 24 to 36 (20-42) narrow linear segments, with the longest segments up to 26 mm (though smaller leaves with fewer segments are sometimes present on early season growth). The segments are usually parallel, and form an angle of less than 45° with the central axis. Emergent leaves are small (1 to 2.3 mm long by 0.6 to 1 (1.5) mm wide), and turn into floral bracts toward the top (with flowers in the axils). Lower emergent leaves are feather-shaped or deeply toothed then abruptly changing to entire (smooth-margined) or shallowly lobed or toothed bracts with the widest part toward the pointed or rounded tip.
Northern watermilfoil: Leaves in whorls of 4, sometimes 3. Either sessile or on very short petioles (to 0.4 mm). Submersed leaves are feather-like (pectinate), with segment pairs at the base of the leaf longer than those at the tip giving the leaf a lance shape. Leaves typically 13 to 32 mm (2.8 to 44 mm) long by (2.1 to) 16 to 35 mm with a blunt or rounded tip. There are generally 6 to 18 (to 24) narrow linear segments, with the longest segments 2 to 20 mm (up to 26 mm). The segments are often perpendicular to central axis but not parallel or in the same

plane, often irregular in orientation. The basal segments are often as long as leaf axis. Emergent leaves are small (1 to 2.3 mm long by 0.6 to 1 mm (to 1.5mm) wide), and turn into floral bracts toward the top (with flowers in the axils). Lower emergent leaves are feather-shaped to deeply lobed, then abruptly transitioning to entire (smooth-margined) or shallowly lobed or toothed bracts with an obovate, elliptic, sometimes spatula-shape in outline, with the widest part toward the pointed or rounded tip.

Hybrid watermilfoil: Leaves with overlapping traits of parents, having 16 -28 leaf segments, and being 16 to 44 mm long (Table 1).

Images: left, Leaf variability in northern (top row), hybrid (middle row) and Eurasian watermilfoil (bottom row), photo credit: S. Parks (Parks et al. 2014); right, close-up of leaves, bottom two are Eurasian watermilfoil, top leaf is native northern watermilfoil (*M. sibiricum*) (Photo Jenifer Parsons).

Winter buds (turions): Eurasian watermilfoil: turions absent.

Northern watermilfoil: turions present, developing the fall. They are typically dark green, cylindrical and have a gradual transition from the normal plant foliage to reduced turions leaves. The leaves are reduced, thickened and stiff compared to the plant's other leaves. Overall size is 12 to 40 mm (to 45mm) long by typically 5 to 12 mm (3 to 15 mm) wide. The tip is +/- rounded. Turion leaves are feather-shaped (pectinate) and strongly appressed to axis at the tip (not at the base) and have clusters of brown, conical trichomes between leaf bases. The leaf is elliptic in outline, 5 to 15 mm long by 1.4 to 5 mm wide. Leaves have 13 to 15 (to 17) segments, with the longest one being 1.8 to 5.2 mm (to 6 mm) long. Basal segment typically less than or equal to half the length of the leaf's central axis with a single, brown conical trichome in each axil. Turions are often visible at the base of new shoots in the following growing season, often being blackish in color. New stem growth from turion tips have leaves that graduate from thickened, compact leaves of the turion to longer, regular looking leaves as the stem grows.

Image: Dark green turion at the stem tip of northern watermilfoil. Photo credit: U Wisconsin Extension.

Hybrid watermilfoil: Turions are occasionally present on the hybrid watermilfoil (R. Thum, personal communication 2015).

Inflorescence: Both species and hybrid: Many flowers are borne on an unbranched stalk to 15 cm long, usually rising above the water surface. Female flowers are at the bottom, and male flowers are at the top, with bisexual flowers in between. Bracts and bracteoles present. Bracts described with emergent leaves. Bracteoles paired, alternate, opposite subtending leaf, cream to purple color with a reddish to brown margin that is entire or toothed or sometimes tipped with a membranous fringe. Flowers are wind pollinated.
Eurasian watermilfoil: bracteoles 0.5 to 0.9 mm long by 0.4 to 0.7 mm wide, usually ovate, sometime obovate or rhombic (diamond) in shape.
Northern watermilfoil: almost naked; bracteoles (0.4 to) 0.6 to 1.3 mm long by 0.4 to 0.7 mm wide, usually ovate, sometimes elliptic to triangular in shape.

Flowers: Both species and hybrid: male and female flowers, either separate or together, sessile in the axils of bracts. Usually in whorls of 4. Flowers have 4 sepals and petals that are small, cream to purplish, often deciduous. Stamens 8. Pistils with 4 styles.
Eurasian watermilfoil: Pistils to 0.9 to 1.2 mm.
Northern watermilfoil: Pistils 1 to 2 mm.

Fruits: Both species and hybrid: Rounded fruits with 4 lobes, divides into 4 mericarps (single seeded structures).
Eurasian watermilfoil: mericarp nearly rounded with tiny warts on dorsal ridges; 1.5 to 2.2 mm long by 0.8 to 1.3 mm wide.
Northern watermilfoil: mericarp nearly round, glabrous or slightly wrinkled; 1.5 to 2.7 mm long by 1.2 to 1.6 mm wide.

Table 1: comparison of three similar watermilfoil species and the hybrid watermilfoil.

	Number of leaflets/leaf	**Leaf length (mm)**	**Winter buds (turion)**	**Bracts on Inflorescence**
Eurasian watermilfoil	24-36 (typical) 20-42 (possible)	18-32 (typical) 14-36 (possible)	No	1-2.3 mm long Margin smooth to shallowly toothed or lobed toward tip
Hybrid	16-28	16-44	Occasional	Assumed same as Eurasian and northern
Northern watermilfoil	6-26	13-32 (typical) 3-44 (possible)	Yes	1-2.3 mm long Margin smooth to shallowly toothed or lobed toward tip
Whorled watermilfoil	12-22 (typical) 9-34 (possible)	12-30 (typical) 7-46 (possible)	yes	2-5 (15) mm long Pectinate with (9) 12-20 segments

Genetic diversity:
Hybrid watermilfoils have resulted from crosses of northern watermilfoil with Eurasian watermilfoil; potentially both of the Eurasian watermilfoil genetically distinct lineages that are known to exist in the United States (Zuellig and Thum 2012). Genetic variation of hybrid watermilfoil can be high, and testing shows hybrids of watermilfoils have formed repeatedly in North America with multiple distinct hybrid clones occurring within many lakes (Zuellig and Thum 2012). Zuellig and Thum (2012) found between 42 and 99 distinct clones (depending on assumed error rate) in North America sampled from 50 populations that contained hybrids.

Research in Idaho found hybrid watermilfoils to be genetically diverse, between lake populations as well as within the same lakes in some cases (Thum 2016). Every waterbody sampled so far in Idaho has had genetically distinct hybrid watermilfoil strains. Where some waterbodies were dominated by one distinct hybrid watermilfoil genotype, such as Hayden Lake, others contained multiple genotypes, such as Lake Coeur D'Alene, which contained 5 hybrid watermilfoil genotypes with one strain being dominant (Thum 2016).

In Washington, testing shows that hybrid watermilfoil populations are present in many waterbodies (see distribution) but these populations have not undergone distinct genotype testing (J. Parsons pers. comm.) Given the research results in Idaho so far, it can be concluded that some of the waterbodies in Washington with hybrid watermilfoil populations probably have multiple genotypes.

Similar Species and Variations:
About eight species of *Myriophyllum* are found in Washington State, three of which are invasive, non-native listed noxious weeds: Eurasian watermilfoil, parrotfeather (*Myriophyllum aquaticum*) and variable leaf milfoil (*Myriophyllum heterophyllum*).

Another watermilfoil species sometimes confused with hybrid, Eurasian and northern watermilfoil species is whorled watermilfoil (*Myriophyllum verticillatum*). When flowering, whorled watermilfoil will have emerged leaves/bracts that are feather-shaped and longer than those of Eurasian watermilfoil (Table 1). In late summer, whorled watermilfoil makes turions that are somewhat club-shaped on stem branches.

Eurasian watermilfoil, as well as northern watermilfoil and hybrid watermilfoil, can vary considerably in leaf size, shape, internode length, and stem color depending on the growing conditions (Arshid and Wani 2013). Plants impacted by herbicide will sometimes form oddly shaped leaves with fused-looking leaflets (Aiken et al. 1979). A terrestrial form of Eurasian watermilfoil will develop where water levels decrease gradually and sediment remains damp. Leaves will be smaller, stiffer and have fewer divisions. When they are re-submersed, new growth will gradually transition to typical submersed leaves (Aiken et al. 1979). In flowing water, Eurasian watermilfoil will have shorter spaces between the leaf whorls and more extensively branched roots resulting in more compact looking plants (Arshid and Wani 2013).

Occasionally, other submersed species with finely divided submersed leaves are confused with Eurasian watermilfoil, northern watermilfoil and hybrid watermilfoil. Presence of the feather-shaped leaf will distinguish watermilfoil species that are found in Washington from other submersed plants.


Image: Eurasian watermilfoil terrestrial growth form (photo K. Messick).

Economic/Ecosystem Importance:

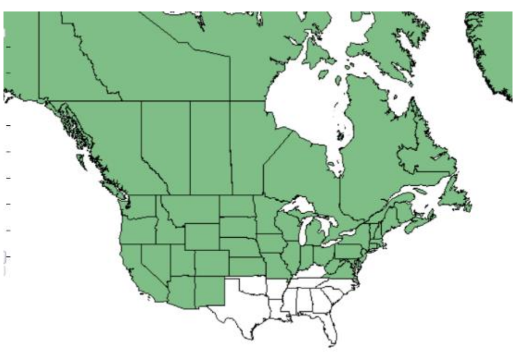
The extent of hybrid watermilfoil distribution in Washington is not yet known. Currently, a number of populations exist in Washington, and more may exist as only limited testing has taken place (J. Parsons pers. comm.). Hybrid watermilfoil grows in the same conditions as Eurasian watermilfoil and can also form dense infestations. Due to its similar growth habit, hybrid watermilfoil could cause the same, and even additional, economic and ecological impacts that result from Eurasian watermilfoil infestations. Aggressive strains of hybrid watermilfoil in Idaho grew faster than Eurasian watermilfoil and were also more tolerant to herbicides (Thum 2016). Further research is needed on hybrid watermilfoil's distribution and ecosystem impacts.

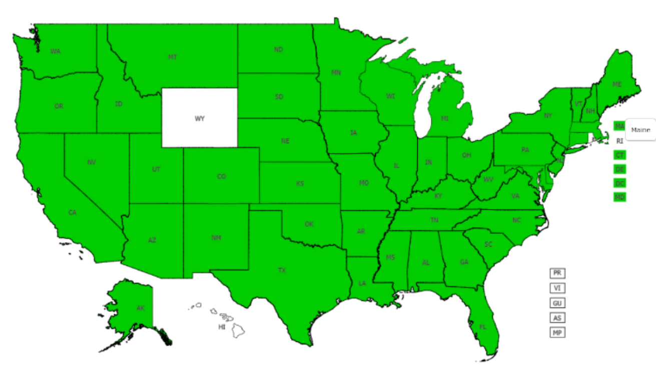
In some lakes and rivers in Washington State, some strains of hybrid watermilfoil do not grow to reach the water surface or dominate the plant community. In those cases its impact is similar to other native aquatic plant species. However, hybrid watermilfoil and Eurasian watermilfoil growth is problematic when dense growth approaches the surface and branches to form a surface mat.
Then, Eurasian watermilfoil, and likely aggressive genotypes of hybrid watermilfoil, can have the following effects:

- impacts dissolved oxygen, and pH due to impeded wind mixing and plant photosynthesis during daylight and respiration at night (Frodge et al. 1990, Aiken et al. 1979)
- Impacts nutrient dynamics of the waterbody (Smith and Barko 1990)
- Increases water temperature (Aiken et al. 1979)
- shades out native vegetation (Madsen et al. 1991)
- impacts habitat for fish and invertebrates:
    - there is evidence that Eurasian watermilfoil produces chemical defenses that will cause some fish and invertebrates to avoid it (Schultz and Dibble 2012)
    - Stunted populations of panfish such as bluegill can result from dense plant beds
    - Piscivorous fish can have reduced fitness due to difficulty catching prey in dense plant beds

    - Native trout and salmon species may be negatively impacted if plants colonize spawning gravels or if they provide increased habitat to invasive predatory fish (Newroth 1985, Dibble et al. 1996, Schultz and Dibble 2012)
- Decreased availability of native plant species that may be more palatable to waterfowl (Aiken et al. 1979)
- Dense growth at or near the surface impedes recreation
- Actual or perceived safety hazard
- Detrimental to property values. One study found a 19% decline in values of lake front property on lakes with Eurasian watermilfoil in the Seattle area (Olden and Tamayo 2014)
- Costs to genetically test and manage invasive hybrid watermilfoil growth are borne by local citizens or state and local governments. Hybrid watermilfoil management can be even more expensive due to the need for repeated genetic testing to track populations.
- As one of hybrid watermilfoil's parents is a native species, norther watermilfoil, hybridization can lead to a reduction of pure northern watermilfoil lineages (Moody and Les 2007).
- With novel genotypes being formed, strains of hybrid watermilfoil that are aggressive have the possibility of being even more invasive than Eurasian watermilfoil (Thum 2016, Berger et al. 2012, Thum et al. 2012).

<u>Geographic Distribution</u>
Hybrid watermilfoil can potentially be found where Eurasian watermilfoil and northern watermilfoil are growing together or had at one time been growing together in the same waterbodies. Eurasian milfoil is native to Europe, Asia and northern Africa. It has spread to almost every state in the U.S. (EDDMapS 2017). Northern watermilfoil's native range includes Canada and all of the United States except for the southeastern states (see map) as well as northern areas of Eurasia.





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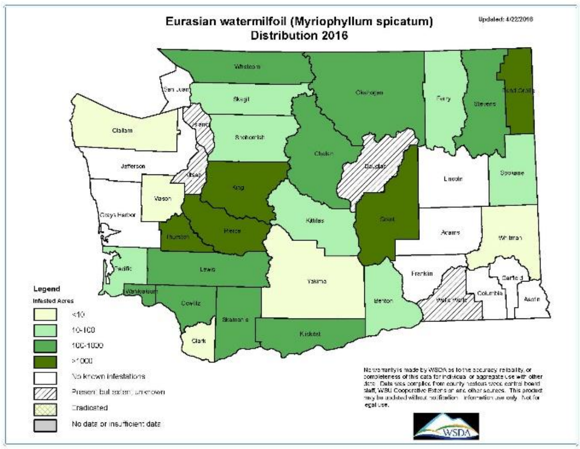
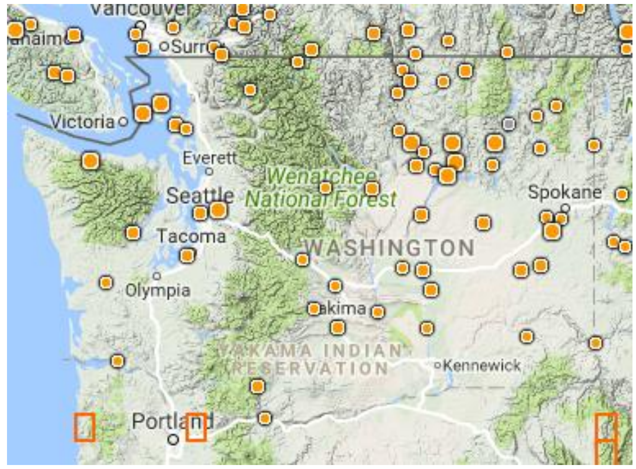
Maps: left, northern watermilfoil, *Myriophyllum sibiricum*, distribution (USDA NRCS 2017); right Eurasian watermilfoil, *Myriophyllum spicatum*, distribution in the United States (EDDMapS 2017).

To date, hybrid watermilfoil has been tested for and found in Idaho, Michigan, Minnesota, Wisconsin, and Washington in the United States and also in Ontario, Canada (Moody and Less 2007, Grafe et al. 2014).

Legal listings: Hybrid watermilfoil (*Myriophyllum spicatum* x *M. sibiricum*) is currently not listed as a noxious weed anywhere in the United States (National Plant Board 2017). Eurasian watermilfoil (*Myriophyllum spicatum*) is listed as a Class B noxious weed in Washington State (WAC 16-750-011), is on the Washington State Quarantine List (WAC 16-752) and is a noxious weed and a quarantined species in many other states.

Washington:





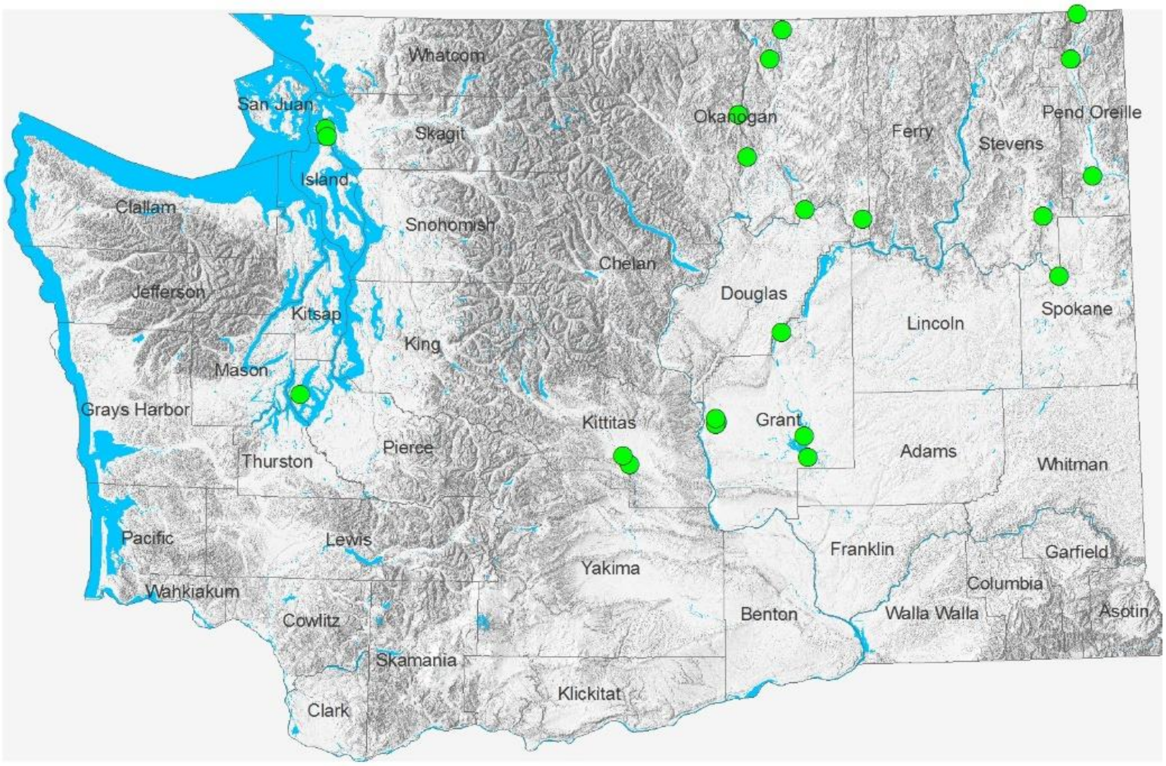
Left, WSDA county level distribution map of Eurasian watermilfoil from 4.22.2016 (WSDA 2016); right, herbarium records of northern watermilfoil throughout Washington State (Consortium of Pacific Northwest Herbaria 2017).

In Washington, Eurasian watermilfoil and northern watermilfoil occur throughout the state. In 2014, Eurasian watermilfoil was known from over 150 lakes throughout the state, the Columbia, Pend Oreille and Snake Rivers, as well as other smaller creeks, rivers and canal systems. Northern watermilfoil is a native plant that commonly grows in lakes, rivers, and ponds and is tolerant of nutrient-rich, alkaline, and brackish water (Hamel et al. 2001). Eurasian watermilfoil and northern watermilfoil grow in a number of the same waterbodies in Washington, and hybrid populations have now been documented in some of these places.

Since its discovery, Jenifer Parsons with the Washington State Department of Ecology has been involved with the testing for hybrid watermilfoil populations, collecting samples of the first two confirmed locations in Washington, at Moses Lake (Grant County) and Conconully (Salmon) Lake (Okanogan County) (Moody and Les 2007). Since then, confirmed hybrid watermilfoil populations are documented at:

- Douglas/Okanogan County: Rufus Woods Lake
- Okanogan: Buffalo Lake, Leader Lake, Osoyoos Lake, Spectacle Lake
- Grant County: Blue Lake, Burke Lake, Corral Lake, Evergreen Lake, Stan Coffin Lake
- Kittitas County: Fiorito Ponds, Mattoon Lake
- Pend Oreille County: Boundary Reservoir, Davis Lake, Pend Oreille River
- Pierce County: Bay Lake
- Skagit County: Campbell Lake, Heart Lake (35N-01E-36)
- Spokane County: Nine Mile Reservoir
- Stevens County: Loon Lake

(J. Parsons pers. comm. 2017).



Map: Locations of hybrid watermilfoil populations of various genotypes in Washington State as of July 2017. Source: Jenifer Parsons, Washington Department of Ecology, 2017).

<u>Habitat</u>
Research is needed to determine the full range of habitat conditions in which hybrid watermilfoil can survive. Currently we know that where northern and Eurasian watermilfoil co-occur and reproduce in Washington State, hybrid watermilfoil should and can be able to form and survive. The following habitat conditions where northern and Eurasian watermilfoil grow can also apply to hybrid watermilfoil.

Northern watermilfoil commonly grows in lakes, rivers, and ponds and is tolerant of nutrient-rich, alkaline, and brackish water (Hamel et al. 2001). In Washington, northern watermilfoil can grow in lakes with over 300 mg/l $caCO_3$ (calcium carbonate) (Parsons 2000).

Eurasian watermilfoil is an adaptable plant, able to tolerate and even thrive in a variety of environmental conditions. It will grow in still to flowing water, including irrigation canals, but won't tolerate high flow or areas prone to high wave action (Arshid and Wani 2013, Smith and Barko 1990). It will grow in water to 10 m deep, and can reach the surface in water up to 5 m deep (Aiken et al. 1979). It tends to form nuisance growths in moderately clear water with moderate nutrient levels. In lakes with very low nutrients, growth will generally be limited to zones with relatively high sedimentation rates and nutrients, such as the mouths of creeks or areas with groundwater upwelling (Smith and Barko 1990). In Washington, it has invaded lakes with a wide alkalinity range (11 to close to 200 mg/l $CaCO_3$), but very low or high alkalinity will limit or exclude its growth (Smith and Barko 1990). It has been reported to tolerate pH from 5.4

to 10 (Aiken et al. 1979). It grows best on fine-textured inorganic sediments of intermediate density (Smith and Barko 1990). Ice scour will prevent it from growing in shallow water of lakes that regularly freeze in winter. It will not survive complete desiccation or freezing (Smith and Barko 1990). It can survive extended periods out of the water if damp (Jerde et al. 2012), and will develop a terrestrial growth form if stranded on damp sediment for an extended period (Aiken et al. 1979). It can tolerate salinities of up to 15 ppt (about half of sea water) (Aiken et al. 1979), and can survive in estuaries where salinity is low; however, at salt concentrations approaching its tolerance (15 ppt) decreased reproductive success in both seed and fragments results, reducing the competitive advantage of Eurasian watermilfoil in those environments (Martin and Valentine 2014).

Growth and Development:

Further research is needed on the growth and development of hybrid watermilfoil, but it is thought to be similar or have many similarities to its parents. While Eurasian watermilfoil does not form specialized overwintering structures, such as turions, turions are occasionally present on the hybrid watermilfoil (R. Thum, personal communication 2015). Also, some shoots persist through the winter and new shoots form in the fall, but do not elongate until spring. Carbohydrate storage occurs throughout these overwintering shoots and roots (Smith and Barko 1990, Madsen 1997).

Eurasian watermilfoil can initiate growth when water temperatures are still cool (10° C), so can start rapid spring growth earlier than some native species (Smith and Barko 1990). Its growth rate will continue to increase with increasing temperature, with optimum growth at about 32° C (Smith and Barko 1990). However, prolonged periods of high water temperature (over 30° C) can cause die-back from temperature stress, as is seen in mid-summer biomass reductions in southern populations and sometimes in shallow lakes of northern populations (Madsen 1997). When Eurasian watermilfoil reaches the surface, shoots branch, forming a surface canopy. Some aggressive hybrid watermilfoil genotypes will branch more profusely than Eurasian watermilfoil, leading to dense surface growth and flowering (Thum personal communication 2015). Flowering occurs at the surface, as flowers are wind-pollinated. As stems elongate, lower leaves are typically shed (Budd et al. 1995). After peak biomass, stems will autofragment (see reproduction below) and biomass will decline (Madsen and Smith 1997).

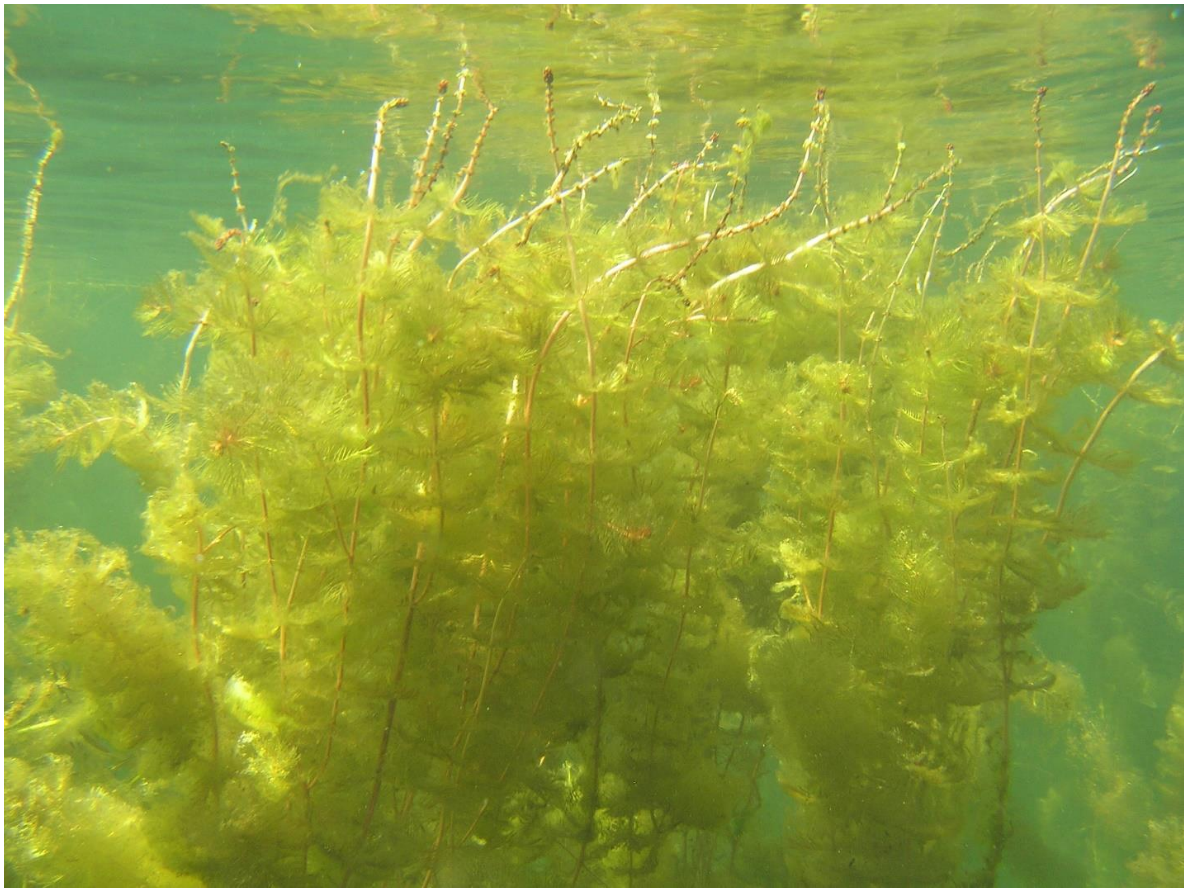


Image: Hybrid watermilfoil underwater growth from Lake Coeur d'Alene, Idaho. Image by Dave Lamb.

Reproduction

Eurasian watermilfoil, northern watermilfoil and hybrid watermilfoil reproduce by sexual and vegetative means (Zuellig and Thum 2012). Though research has primarily been conducted on Eurasian watermilfoil, hybrid watermilfoil is thought to reproduce in much the same way as its parents.

Vegetative reproduction

Vegetative spread is generally considered the major method of reproduction within a waterbody, and is accomplished by three mechanisms: stolons (rhizomes), autofragments and allofragments. In studies on hybrid watermilfoil, it has been noted to readily root from fragments (Thum, personal communication 2015). Stolons are the most successful, and account for the majority of colony expansion in the immediate area of parent plants. Autofragments are typically created in late summer when short (15 to 20 cm) sections of the stem tips will develop roots and automatically separate from the parent plants. Northern watermilfoil does not form autofragments (Aiken et al. 1979) (though fragments formed by disturbance will root and start new plants). It is assumed hybrid watermilfoil would be variable in this characteristic. Allofragments are created by mechanical disturbance of plants such as from wave action or boat propellers. Those broken sections of stem will then form roots and settle to the bottom. The autofragments are higher in energy reserves, and thus will have higher success in developing into new plants than allofragments (Madsen and Smith 1997). Autofragment creation is higher on low nutrient sediments, thus allowing plant fragments to float off and seek different environments. On higher nutrient sediments, the plants put more energy into root and stem growth, allowing for expansion in the immediate area (Smith et al. 2002).

Jerde et al. (2012) found that Eurasian watermilfoil fragments survived well after one hour of drying, and fragments that were coiled around something like a prop survived up to 5 hours of desiccation. Temperature and humidity would influence this survival, but this ability has led to vegetative spread between lakes.

Seed Production

Genetic analysis shows that sexual reproduction occurs frequently in Eurasian watermilfoil and hybrid watermilfoil, and can facilitate spread through seed in addition to the well-known vegetative spread by fragments (Zuellig and Thum 2012). Eurasian watermilfoil seed production can be significant. In one study, up to 48 flowers were produced per flower stem with an average percent seed set between 1 and 24% (Madsen and Boylen 1989). Seed production was higher in a low nutrient lake when compared with a moderately eutrophic lake, indicating that plants put more resources into long-distance dispersal by seed when resources are limited (Madsen and Boylen 1989).

Eurasian watermilfoil seed germination requires water temperatures above 10° C, with a maximum germination rate reached at about 20° C with 14 hours of daylight (although seeds also germinate without light). Drying decreases the ability of seeds to germinate. However, even after 36 weeks of dry time, some seeds were still viable; indicating that seed production can be a means for drought survival (Standifer and Madsen 1997). Seeds buried under greater than 2 cm of sediment showed a much reduced germination rate, as did seeds in areas of high water movement from waves or recreational disturbance. Thus, seedlings are more likely to establish in areas of deep calm water (Hartleb et al. 1993).

Control Strategies

Many studies have taken place on Eurasian watermilfoil control, and a number of recent studies have been conducted with the confirmation of the existence of hybrid watermilfoils. The best results are usually attained by using a combination of methods, a practice known as Integrated Pest Management. The methods chosen should depend on the characteristics of the water body where the hybrid watermilfoil is growing, the size of the hybrid watermilfoil population, and the desired end result.

Due to the genetic diversity of hybrid watermilfoil, responses to control may vary. The hybrid is really a genetically diverse group of many unique crossings and back-crossings, leading to the potential for variable responses to control methods. Both herbicide control response and response to herbivorous insects have been shown to be variable depending on the hybrid strain. Therefore, recent recommendations include testing for hybrid strains prior to treatment, particularly with herbicides, to potentially tailor treatment and reduce the chance of selecting for more tolerant hybrid strains (Parks et al. 2014, Schulte and Thum 2014).

Thum (2016) recommends the following management steps for actively managing hybrid watermilfoil infestations.

1. Conduct a genetic survey for each water body to identify how many and which genotypes are present. Map the genotypes against any known treatment history information to see if it can be determined which genotypes are more aggressive.
2. When possible, conduct growth and herbicide studies to determine if plants are susceptible to or unusually tolerant of proposed herbicides.
3. Monitoring of control measures as operational costs allow and adapting management methods where needed.
4. Genetic monitoring before and after treatment to evaluate the changes in genetic composition, signaling if hybrids with more aggressive genotypes (tolerant of herbicide, faster growing) have an increase in relative abundance.
5. Repeat entire process as necessary and eventually moving to a maintenance level or eradication if possible.

Cultural Methods
These cultural control methods are recommended and written for controlling Eurasian watermilfoil and can also be used when hybrid watermilfoil is present.

Bottom barrier - Covering patches of Eurasian watermilfoil and hybrid watermilfoil with geotextile fabric or other similar woven material can be an effective control method. One study showed control of Eurasian watermilfoil was achieved while native species grew back with an 8-week cover period. They also found that Eurasian watermilfoil fragments would root and establish with 4 cm (1.5 inches) of sediment on top of the barrier material, so barrier maintenance is required (Laitala et al. 2012). Barriers can also trap gas from decomposing plants beneath them and balloon up, requiring additional maintenance.

Drawdown – Water level reduction to expose plant beds to extended drying or freezing can be an effective hybrid watermilfoil and Eurasian watermilfoil control method. Winter drawdown is the most commonly used method, and will kill existing watermilfoil so long as the plants and roots freeze. Snow pack or residual water can protect plants and reduce effectiveness (Stanley 1976). Winter drawdown is used annually in Lake Spokane and other reservoirs in Eastern Washington to control Eurasian watermilfoil.

Hot Water – Blumer et al. (2009) found that water temperature of 60° C (140 F) was required to consistently kill Eurasian watermilfoil fragments. This research was to determine effectiveness of hot water washing to clean boats.

Manual and Mechanical Methods
These manual and mechanical control methods are recommended and written for controlling Eurasian watermilfoil and can also be used when hybrid watermilfoil is present. All methods of Eurasian watermilfoil and hybrid watermilfoil control that involve physically handling plants require careful containment and removal of plant fragments.

Hand-pulling: Hand-pulling by divers successfully controlled Eurasian watermilfoil in a large lake in New York, but costs were high (about $350,000/year for intensive management during the first years of the program, and $150,000/year for maintenance) (Kelting and Laxon 2010).

Divers are often used to successfully control or eliminate small populations of Eurasian watermilfoil in Washington lakes – either when a population is small or after using another control method such as herbicides to reduce its size. These divers often use a barge-mounted suction hose to take plants from where they are hand-pulling to the boat to increase efficiency. Hand-pulling while wading or snorkeling can be effective in shallow areas so long as the roots are removed and by making sure to collect any fragments.

Cutting and Harvesting: Mechanical harvesters, cutters and raking will generally not remove the roots, so the plants will grow back. These methods also lead to extensive fragmentation, so should only be used where Eurasian watermilfoil is already widespread. These methods are sometimes used to provide immediate relief from extensive surface mats.

Rotovation: Rotovation is like underwater rototilling, and will remove watermilfoil roots. Use of these machines is restricted due to the high level of sediment disturbance. A rotovator has been used for many years in the Pend Oreille River, with watermilfoil control generally lasting two years after treatment.

Biological Control

Biological control is the use of natural enemies such as insects and diseases to reduce the damage caused by a pest such as an invasive non-native plant.

The milfoil weevil, *Euhrychiopsis lecontei*, while native to the United States, is the most promising insect found to use as a biocontrol on Eurasian watermilfoil. This weevil is native to the northern part of the United States, including Washington (Tamayo et al. 1999). The weevil's native host is northern watermilfoil; however, if the weevil is reared on Eurasian watermilfoil, it will prefer it over northern watermilfoil. The weevils spend their entire life cycle on water. The adults eat leaves on the growing tips, and larvae mine into the stem causing a reduction in plant buoyancy (Newman 2004). Hybrid watermilfoil responds variably to the milfoil weevil. Some studies have found the hybrid to be less susceptible to grazing, while other studies have found the hybrid to have a similar response to Eurasian watermilfoil. This variation likely results from variability in the genetic make-up of various hybrid strains (Borrowman et al. 2015).

Other insects that have been shown to reduce Eurasian watermilfoil growth include the milfoil midge *Cricotopus myriophylli*, the caddisfly *Triaenodes tardus,* and the moth larvae *Acentria ephemerella*. The weevil, midge and caddisfly are all known from Washington State, and have shown they can be effective at reducing Eurasian watermilfoil abundance (Parsons 2012), though like the milfoil weevil, have variable results on hybrid watermilfoil.

Most biological control programs rely on releases of a relatively small number of insects as founding populations, then allow natural reproduction to build over the course of several years to accomplish a reduction in the host plant. Because the insects known to control Eurasian watermilfoil are naturally occurring, and because rearing them is time consuming and sometimes difficult, and there is no local source to purchase them at this time, we rely on natural dispersion to aid with Eurasian watermilfoil control.

Triploid grass carp are a non-host specific biocontrol alternative. However, these fish do not prefer Eurasian watermilfoil over native species, so will typically eat the native plants prior to Eurasian watermilfoil. It is not known if or under what conditions the tripoloid grass carp would feed on hybrid watermilfoil, but since they do not prefer Eurasian watermilfoil or northern watermilfoil, they may not prefer the hybrid either. Therefore they are not recommended for Eurasian watermilfoil or hybrid watermilfoil control.

Herbicide Control

Note: Use of pesticides in water is regulated in Washington State. All applicators must have an aquatic endorsement on their pesticide applicators license, which is issued by the Washington Department of Agriculture. In addition, coverage under a permit issued by the Department of Ecology is required. See http://www.ecy.wa.gov/programs/wq/pesticides/index.html for details.

Herbicide control has been shown to be variable for hybrid watermilfoil. Due to their genetic variability, hybrid watermilfoil may be tolerant of certain herbicides and at various strengths. For example, hybrid populations with different genotypes have been found to be more tolerant to 2,4-D and triclopyr (Glomski and Netherland 2010; LaRue et al. 2013, Netherland and Willey 2017). Netherland and Willey (2017) found two hybrid populations had increased tolerance of a 2,4-D treatment, using one-eighth the maximum allowable concentration, but did result in overall control at a long exposure time of 144 hours in a controlled setting. A hybrid population from Townline Lake in central Michigan was found to be tolerant to fluridone (Berger et al. 2012; Thum et al. 2012 in Berger et al. 2015). The same Townline Lake hybrid population was also found to be tolerant of diquat, when tested at its maximum allowable concentration, while the biomass of two other hybrid populations was greatly reduced by the same treatment (Netherland and Willey 2017). Therefore, recent recommendations include testing for hybrid strains prior to treatment to potentially tailor treatment rates, and reduce the chance of selecting for more herbicide tolerant hybrid strains (Parks et al. 2014, Schulte and Thum 2014).

Many herbicide trials have shown that several products are effective at controlling Eurasian watermilfoil and can also be used on hybrid watermilfoil though the concentration needed may vary due to the hybrid genotype. Keep in mind that when applied directly to water, herbicides will dissipate. Therefore, both the herbicide concentration, and the amount of time the plants are exposed to the herbicide can influence efficacy. Factors such as current, wind, and sub-surface springs can all affect exposure times. Also, the depth of the lake's thermocline will affect herbicide mixing (Getsinger et al. 2001), and often plants in cold deep water will not be controlled. For some products, studies have been done to recommend different concentrations based on expected exposure time (Table 2).

Below is a general summary by herbicide type and active ingredient for Eurasian watermilfoil, which can also apply to hybrid watermilfoil, but refer to the literature for more complete details. Genetic testing and an increase in herbicide concentrations and/or exposure times may be needed if aggressive hybrid watermilfoil genotypes are present. Only herbicides allowed for use in water under Washington's NPDES permits are included.

Contact Herbicides - typically 'burn' the plant back, but don't translocate to roots so may not kill the entire plant. Plants will die back quickly, so treating early in the season prior to peak biomass will reduce the risk of low oxygen as plants break down. If the target weed patches are large, treat incrementally to further reduce risks of problems (fish stress or kills) from low oxygen.

- Carfentrazone-ethyl: Used alone, there have been conflicting outcomes in the literature. Its effectiveness is affected by temperature and pH, so those variables may be part of the reason for the inconsistency. However, one study got excellent Eurasian watermilfoil control using Carfentrazone at 100 µg/l combined with a low rate of 2,4-D (100 µg/l) (Gray et al. 2007).
- Flumioxazin: Used alone, concentrations of 200-400 ppb ai (active ingredient) are recommended. Glomski and Netherland (2013) saw little difference in Eurasian watermilfoil response between those two concentrations. Flumioxazin breaks down quickly if pH is more than 8.5, thus test pH prior to use, and treat early in the morning when pH is lowest (pH can swing widely in plant beds due to the photosynthetic process) (Valent Professional Products 2012 a).
- Diquat: Excellent control resulted from experimental treatments at both .37 mg/l and .19 mg/l (Wersal et al. 2010). Diquat binds quickly to sediment, so is not recommended for treatment in turbid water conditions. Netherland and Willey (2017) found that a strain of hybrid watermilfoil known to be aggressive showed tolerance to diquat treatments while other hybrid strains were susceptible. If a population isn't responding as anticipated, genetic analysis and testing for sensitivity of that particular population is warranted.
- Endothall (dipotasium salt): Endothall can provide excellent control of Eurasian watermilfoil. In an experiment on a small Washington lake, endothall at low concentrations (1.5 mg/l) was selective, and provided at least three years of Eurasian watermilfoil control while leaving most native aquatic plants unharmed (Parsons et al. 2004).

Systemic Herbicides – will move throughout the plant tissue, therefore generally provide good long-term control. However, often less than 100% of the Eurasian and/or hybrid watermilfoil will be killed with one application due to water movement or other issues, so repeat treatments or follow-up with hand-pulling may be necessary to achieve eradication. Some are selective for certain types of plants (e.g. broadleaf plants like hybrid water watermilfoil and Eurasian watermilfoil) or selectivity can be achieved by using low rates.

- 2,4-D (amine and ester): 2,4-D selectively kills broadleaf plants, thus can be used to kill Eurasian watermilfoil and susceptible genotypes of hybrid watermilfoil while leaving native pondweeds and rushes. There are two formulations, an ester and an amine. The ester has more use restrictions (see http://www.ecy.wa.gov/programs/wq/pesticides/postTreatmentGuidelines.html). The use of even lower rates can also be effective if exposure times are extended (Glomski and Netherland 2010). 2,4-D has also been combined with contact herbicides such as endothall, carfentrazone-ethyl and flumioxazin to reduce both the concentration of herbicide required and the exposure time. Hybrid watermilfoil has the potential to develop resistance to 2,4-D (Schulte and Thum 2014). If a population isn't responding as anticipated, genetic analysis and testing for sensitivity of that particular population is warranted. 2,4-D has been used to successfully control and even eradicate Eurasian watermilfoil from several Washington lakes.

- Bispyribac-sodium is a slow acting systemic herbicide which requires a long exposure time (60 to 90 days). Applications are commonly done multiple times, with the initial application followed by 'bump' applications to maintain the herbicide concentration, similar to fluridone. Therefore this product is not for use in flowing water situations (Hamel 2012). The product label (Tradewind ®) lists Eurasian watermilfoil as one of the submersed plants it controls (Valent Professional Products 2012 b).
- Fluridone is a slow acting systemic herbicide. It can be used at low rates (5 µg/l) for selective lake-wide Eurasian watermilfoil control so long as that concentration is maintained for the contact time (> 60 days). This generally requires an initial herbicide application followed by 'bump' applications, and utilization of a water test to determine herbicide concentrations during treatment. In Washington, whole lake fluridone treatments followed by spot treatment of surviving patches with faster acting herbicides or hand pulling have successfully eradicated Eurasian watermilfoil. So far, one hybrid watermilfoil genotype has been found that is more tolerant to fluridone, while other hybrid genotypes were susceptible (Berger et al. 2012, Thum et al. 2012). If a population isn't responding as anticipated, genetic analysis and testing for sensitivity of that particular population is warranted.
- Imazamox is a somewhat selective fast acting systemic herbicide. While imazamox typically controls grasses more effectively than broad-leaf plants, the product label (Clearcast ®) includes Eurasian watermilfoil as susceptible at concentrations of 50 to 200 ppb if applied early in the growing season when plants are actively growing (SePRO Corp 2013 a). Several studies have shown imazamox to provide Eurasian watermilfoil control at rates between 100 to 200 ppb (Hamel 2012).
- Penoxsulam is a slow acting systemic herbicide similar to Bispyribac-sodium. It requires a 60 to 120 day contact time, with longer times required when plants are not rapidly growing. Typical application rates for penoxsulam are 10-20 ppb in an initial treatment with additional "bump" applications of 5-10 ppb to keep the water concentrations at 5-10 ppb for 45 to 90 days. The sum of all applications may not exceed 150 ppb per year (Hamel 2012). The product label (Galleon SC®) includes Eurasian watermilfoil in its list of controlled plants (SePRO Corp 2013 b).
- Triclopyr is a selective herbicide that targets broad leaf plants and works well for Eurasian watermilfoil control while leaving native pondweeds unharmed. In addition, early season treatments can improve selectivity if exposure times are adequate (Netherland and Glomski 2014). The use of even lower rates can also be effective if exposure times are extended, but different hybrid watermilfoil genotypes respond differently to the low herbicide concentrations (Glomski and Netherland 2010). If a population isn't responding as anticipated, genetic analysis and testing for sensitivity of that particular population is warranted. Triclopyr has been combined with contact herbicides to also increase efficacy with reduced contact times (Getsinger et al. 2013).

Herbicide combinations have been shown to often provide more effective control with lower concentrations of herbicide. Combinations that have been shown to work well for Eurasian watermilfoil are:
Carfentrazone-ethyl + 2,4-D (Gray et al. 2007)
Endothall + triclopyr (Getsinger et al. 2013)

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