WRITTEN FINDINGS OF THE
WASHINGTON STATE NOXIOUS WEED CONTROL BOARD

Scientific Name: *Myriophyllum spicatum* L.

Common Name: Eurasian watermilfoil, Eurasian milfoil

Family: Haloragaceae

Legal Status: Class B:
(a) Region 1 except Pacific and Mason Counties
(b) Island and San Juan Counties of Region 2
(c) Clark and Cowlitz Counties of Region 3
(d) Chelan and Okanogan counties and all lakes with public boat launches except Fan Lake in Pend Oreille County of Region 4
(e) Adams and Lincoln counties of region 5
(f) Asotin, Columbia and Garfield counties of region 6

Additional Listing: Washington State quarantine list (WAC16-752)

LEFT: Eurasian watermilfoil mat with flower stems, MIDDLE: typical stem and stem cross-section showing 4 leaves, RIGHT: close-up of leaves, bottom two are Eurasian watermilfoil, top leaf is native northern watermilfoil (*M. sibiricum*) (Photos J. Parsons).

Description and Variation:

Eurasian watermilfoil (EWM) is a submersed perennial plant with feather-like submersed leaves and flower stems with small flowers and very small leaf-like bracts that typically rise above the water surface. There are several native water-milfoil species that look similar to EWM so identification can be challenging. In addition, it will hybridize with the native northern watermilfoil (*Myriophyllum sibiricum* Kom.) (here-on called 'hybrid') and have intermediate characteristics that can overlap with both parents (Table 1). Therefore genetic analysis is sometimes relied on for definitive species identification.

Unless otherwise noted, below descriptions are from Scribailo and Alix 2014, and Douglas et al. 1999.

Roots: 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: terete (round in cross-section), glabrous (without hairs) from pale greenish-tan to red in color, often highly branched at or near the water surface, up to 6 m long.

Leaves: Usually grow in whorls of 4, though occasionally 3 to 5. Either sessile or on very short petioles (to 0.4 mm). Two types – 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 ones feather-shaped or deeply toothed then abruptly changing to entire (smooth-margined) or shallowly tooth leaves with the widest part toward the pointed or rounded tip. The hybrid leaf has 16 -28 leaf segments, and is 16 - 44 mm long (Table 1).

Winter buds (turions): absent in EWM, occasionally present in the hybrid (R. Thum, personal communication 2015).

Inflorescence: 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 are paired, tiny (0.5 x 0.4 mm to 0.9 x 0.7 mm), 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.

Flowers: male and female flowers, either separate or together, sessile in the axils of bracts. Usually in whorls of 4. 4 sepals and petals, small (to 1 mm), cream to purplish, often deciduous. Stamens 8. Pistils to 1.2 mm with 4 styles.

Fruits: 4 rounded mericarps, with dorsal ridges and bumps, to 2.2 mm long

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

	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

Similar Species and Variations:

Occasionally other submersed species with finely divided submersed leaves are confused with EWM. Presence of the feather-shaped leaf will distinguish milfoil species that are found in Washington from other submersed plants.

About eight species of *Myriophyllum* are found in Washington State, three of which are invasive, non-native listed noxious weeds (EWM, parrotfeather (*Myriophyllum aquaticum*) and variable leaf milfoil (*Myriophyllum heterophyllum*)). Unfortunately several of the species are similar in appearance, and some are known to hybridize. Therefore, correct identification is critical.

The species most commonly confused with EWM is northern milfoil. Northern milfoil can be distinguished from EWM by the number of leaflets (less than 24 per leaf) and 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 (Table 1). Early season leaf growth and leaves on floating fragments of EWM often resemble northern milfoil. In the late summer and fall, northern milfoil will form turions (overwintering buds) at the stem tips that look like short segments of dark, densely crowded leaves (EWM does not form turions).

Hybrids will form between EWM and northern watermilfoil, and are increasingly common in Washington State. They have intermediate characteristics, including a variable number of leaflets usually in a range of overlap between northern and Eurasian milfoil, 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 backcrossed 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).

LEFT: Leaf variability in northern (top row), hybrid (middle row) and Eurasian watermilfoil (bottom row). Photo credit: S. Parks (Parks et al. 2014). RIGHT: Turion at the stem tip of northern milfoil. Photo credit U Wisconsin Extension.

The other milfoil species sometimes confused with EWM is whorled watermilfoil (*Myriophyllum verticillatum*). When flowering, whorled watermilfoil will have emerged leaves/bracts that are feather-shaped and longer than those of EWM (Table 1). In late summer, whorled watermilfoil makes turions that are some-what club-shaped on stem branches.

As a species EWM 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 EWM 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, EWM will have shorter spaces between the leaf whorls and more extensively branched roots resulting in more compact looking plants (Arshid and Wani 2013).

Eurasian milfoil terrestrial growth form (photo K. Messick)

Economic/Ecosystem Importance:

In some lakes and rivers in Washington State, EWM does not grow to reach the water surface or dominate the plant community (usually due to water level variation or suppression by native herbivorous insects, see control section below). In those cases its impact is similar to other native aquatic plant species. However, EWM growth is problematic when dense growth approaches the surface and branches to form a surface mat. Then it 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 EWM produces chemical defenses that will keep 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 EWM in the Seattle area (Olden and Tamayo 2014)
- Costs to manage invasive EWM growth are borne by local citizens or state and local governments.

Geographic Distribution

Eurasian milfoil is native to Europe, Asia and northern Africa. It was introduced to North America by at least 1942 (Couch and Nelson 1985) and has spread to 4 Canadian provinces and 45 States (Scribailo and Alex 2014).

Habitat

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). Though 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 EWM in those environments (Martin and Valentine 2014)

History

Eurasian watermilfoil may have been introduced to the North American continent at Chesapeake Bay in the 1880's, although Couch and Nelson (1985) present evidence that the first collection was made in the Washington D.C. area in 1942. By 1985 EWM had been found in 33 states and 3 Canadian provinces, and by 2014 it was known from 45 states and 4 provinces (Scribailo and Alix 2014). Genetic analysis has revealed presence of at least two strains of EWM in the US, leading to the assumption that it was introduced from two parent populations (Zuellig and Thum 2012). The first known record of EWM in Washington State is from an herbarium specimen collected from Lake Meridian in King County in 1965. However, state officials became aware of EWM as a problem plant in 1974 when EWM moved downstream from the Canadian Okanogan Lakes into Lake Osoyoos on the U.S. border. In spite of efforts to prevent its spread, EWM moved downstream into the Okanogan River and the Columbia River. From there it spread to many other lakes and rivers in eastern Washington. In western Washington EWM was found in Lake Washington in 1974 and has spread from there into many additional lakes. In 2014 EWM 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.

Growth and Development:

Eurasian watermilfoil is essentially evergreen, though dies back in winter. It forms no specialized overwintering structures such as turions. Instead, 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). It 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 EWM reaches the surface, shoots branch, forming a surface canopy. 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).

Note on hybrid: the some aggressive hybrid strains will branch more profusely than EWM, leading to dense surface growth and flowering (Thum personal communication 2015).

Reproduction

Eurasian watermilfoil reproduces by both sexual and vegetative means.

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. 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. 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 EWM 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 is ability has led to vegetative spread between lakes.

Note on Hybrid: Northern milfoil does not form autofragments (Aiken et al. 1979) (though fragments formed by disturbance will root and start new plants). It is assumed the hybrid would be variable in this characteristic. In studies on the hybrid, it has been noted to readily root from fragments (Thum, personal communication 2015).

Seed Production

Genetic analysis shows that sexual reproduction occurs frequently in EWM and the hybrid, 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).

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 EWM control. 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 EWM is growing, the size of the EWM population, and the desired end result.

Note on hybrids. Hybrid milfoil is present in many Washington lakes, and their presence has the potential to confound control. Identification can be very difficult, requiring genetic analysis to be certain (see Description and Variation section). The hybrid is really a genetically diverse group of many unique crossings and back-crossings of Eurasian and northern milfoil, 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)

Cultural Methods

Bottom barrier - Covering patches of EWM with geotextile fabric or other similar woven material can be an effective control method. One study showed control of EWM was achieved while native species grew back with an 8-week cover period. They also found that EWM 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 EWM control method. Winter drawdown is the most commonly used method, and will kill existing EWM 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 EWM.

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

Manual and Mechanical Methods

All methods of EWM control that involves physically handling plants requires careful containment and removal of plant fragments.

Hand Pulling - Hand harvesting by divers successfully controlled EWM 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 EWM 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.

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 EWM 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 milfoil 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 milfoil 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. Over the years research on biocontrol agents in Eurasian watermilfoil's native range have been conducted by various agencies, but a promising insect proved elusive. During that time, natural declines in EWM abundance in the Northeast US and British Columbia led to research on herbivorous insects already present in the US.

The most promising of those insects was the milfoil weevil, *Euhrychiopsis lecontei.* 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 EWM it will prefer it over northern milfoil. The weevils spend their entire life cycle on milfoil. The adults eat leaves on the growing tips, and larvae mine into the stem causing a reduction in plant buoyancy (Newman 2004).

Other insects that have been shown to reduce EWM 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 EWM abundance (Parsons 2012). In fact, if their numbers are high, EWM will be a relatively minor member of the submersed plant community. However, the insects are vulnerable to fish predation and various other environmental factors that limit their abundance, so they cannot thrive under all conditions. This is evidenced by the fact that EWM is still a problem in some areas.

Note on hybrid: Hybrid milfoil can respond variably to herbivores such as 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 EWM. This variation likely results from variability in the genetic make-up of various hybrid strains (Borrowman et al. 2015).

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 EWM 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 EWM control.

Triploid grass carp are a non-host specific biocontrol alternative. However, these fish do not prefer EWM over native species, so will typically eat the native plants prior to EWM. Therefore they are not recommended for EWM or hybrid milfoil 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.

Many herbicide trials have shown that several products are effective at controlling EWM. 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).

Note on hybrid: Herbicide control response has been shown to be variable for hybrid milfoil. Therefore, recent recommendations include testing for hybrid strains prior to treatment to potentially tailor treatment rates, and reduce the chance of selecting for more tolerant hybrid strains (Parks et al. 2014, Schulte and Thum 2014)

Below is a summary by herbicide type and active ingredient, but refer to the literature for more complete details. 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 EWM 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 EWM 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.
- Endothall (dipotasium salt): Endothall can provide excellent control of EWM. See Table 2 for recommended concentration and exposure times (Netherland et al. 1991). In an experiment on a small Washington lake, endothall at low concentrations (1.5 mg/l) was selective, and provide at least three years of EWM 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 EWM 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 EWM) 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 EWM 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). Studies have been done to determine concentration and exposure time recommendations (Table 2). 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. 2,4-D has been used to successfully control and even eradicate EWM from several Washington lakes. Hybrid milfoil 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.

- 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 EWM 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 EWM 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 EWM. However, on a cautionary note, one hybrid strain has been found that is more tolerant to fluridone than EWM, while other hybrids are not (Thum et al 2012).
- 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 EWM 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 EWM 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 EWM in its list of controlled plants (SePRO Corp 2013 b).
- Triclopyr is a selective herbicide that targets broad leaf plants and works well for EWM control while leaving native pondweeds unharmed. Concentration and exposure time studies have been done (Table 2) to improve predictability of results. 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 (Glomski and Netherland 2010). 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 EWM are:
Carfentrazone-ethyl + 2,4-D (Gray et al. 2007)
Endothall + triclopyr (Getsinger et al. 2013)

Table 2: Concentration and exposure time recommendations for three herbicides.

Herbicide	Degree of Control	concentration	exposure
Triclopyr (Netherland and Getsinger 1992)	excellent control (>85% biomass reduction)	.25 mg/l	72 hr
		0.5 mg/l	48 hr
		1 mg/l	36 hr
		1.5 mg/l	24 hr
		2 mg/l	18 hr
endothall (dipotasium salt) (Netherland et al. 1991)	excellent control (85% biomass reduction)	0.5 mg/l	48 hr
		1 mg/l	36 hr
		3 mg/l	18 hr
		5 mg/l	12 hr
2,4-D Green and Westerdahl 1988)	control (near 100%)	1 mg/l	48 hr
		2 mg/l	36 hr
	severe injury	0.5 mg/l	72 hr
		1 mg/l	36 hr
		2 mg/l	24 hr

References

Aiken, S.G., P.R. Newroth, I. Wile. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum* L. Canadian Journal of Plant Science 59:201-215.

Arshid, S., A.A. Wani. 2013. Phenotypic plasticity, clonal architecture and biomass partitioning in *Myriophyllum spicatum* L. across different lentic and lotic ecosystems of Kashmir. African Journal of Biotechnology 12(19):2618-2623.

Blumer, D.L., R.M. Newman, F.K. Gleason. 2009. Can hot water be used to kill Eurasian watermilfoil? Journal of Aquatic Plant Management. 47:122-127.

Borrowman, K.R., E.P.S. Sager, R.A. Thum. 2015. Growth and developmental performance of the milfoil weevil on distinct lineages of Eurasian watermilfoil and a northern x Eurasian hybrid. Journal of Aquatic Plant Management. 53:81-87.

Budd, J., R.A. Lillie, P. Rasmussen. 1995. Morphological characteristics of the aquatic Macrophyte, *Myriophyllum spicatum* L., in Fish Lake, Wisconsin. Journal of Freshwater Ecology 10(1): 19-31.

Couch R., E. Nelson. 1985. *Myriophyllum spicatum* in North America. *In* L.W.J. Anderson (ed), Proceedings: 1st International Symposium on Watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C. pp. 8-18.

Dibble, E.D., K.J. Killgore, S.L. Harrel. 1996. Assessment of fish-plant interactions. Miscellaneous Paper A-97-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS. 20 pp.

Douglas, G.W., D. Meidinger, and J. Pojar (Ed.). 1999. Illustrated Flora of British Columbia: Volume 3 Dicotyledons (Diapensiaceae through Onagraceae). B.C. Ministry Environment, Lands and Parks, and B.C. Ministry Forests. Victoria, B.C. 427 pp. (*Myriophyllum* pp 228-235)

Frodge, J.D. G.L. Thomas, G.B. Pauley. 1990. Effects of canopy formation by floating and submergent aquatic macrophytes on the water quality of two shallow Pacific Northwest lakes. Aquatic Botany 38:231-248.

Getsinger, K.D., J.D. Madsen, T.J. Koschnick, M.D. Netherland, R.M. Stewart, D.R. Honnell, A.G. Staddon, C.S. Owens. 2001. Whole-lake applications of Sonar™ for selective control of Eurasian watermilfoil. ERDC/TR-01-7. Vicksburg, MS: US Army Engineer Research and Development Center.

Getsinger, K. D., J. D. Madsen, R. M. Wersal, J. G. Skogerboe, J. J. Nawrocki, R. J. Richardson, and M. R. Sternberg. 2013. Selective control of Eurasian watermilfoil and curlyleaf pondweed in Noxon Rapids Reservoir, Montana: Aquatic herbicide evaluations 2009-2010. ERDC/EL TR-13-5. Vicksburg, MS: US Army Engineer Research and Development Center.

Glomski L.M., M.D. Netherland. 2010. Response of Eurasian and hybrid watermilfoil to low use rates and extended exposures of 2,4-D and triclopyr. Journal of Aquatic Plant Management. 48:12-14.

Glomski, L.M., M. D. Netherland. 2013. Use of a small-scale primary screening method to predict effects of flumioxazin and carfentrazone-ethyl on native and invasive submersed plants. Journal of Aquatic Plant Management. 51:45-48.

Gray, C.J., J.D. Madsen, R.M. Wersal, K.D. Getsinger. 2007. Eurasian watermilfoil and parrotfeather control using Carfentrazone-ethyl. Journal of Aquatic Plant Management 45:43-46.

Green, W.R., H.E. Westerdahl. 1988. 2,4-D concentration and exposure time relationships for the control of Eurasian watermilfoil. Miscellaneous Paper A-88-8. US Army Engineer Waterways Experiment Station, Vicksburg, MS

Hamel, K. 2012. Environmental Impact Statement for Penoxsulam, Imazamox, Bispyribac-sodium, Flumioxazin and carfentrazone-ethyl. Washington Department of Ecology, Olympia. WA. https://fortress.wa.gov/ecy/publications/publications/0010040addendum1.pdf

Hartleb, C.F., J.D. Madsen, C.W. Boylen. 1993. Environmental factors affecting seed germination in *Myriophyllum spicatum* L. Aquatic Botany. 45:15-25.

Jerde, C.L, M.A. Barnes, E.K. DeBuysser, A. Noveroske, W.L. Chadderton, D.M. Lodge. 2012. Eurasian watermilfoil fitness loss and invasion potential following desiccation during simulated overland transport. Aquatic Invasions 7(1):135-142.

Kelting, D.L., C.L. Laxson. 2010. Cost and effectiveness of hand harvesting to control the Eurasian watermilfoil population in upper Saranac Lake, New York. Journal of Aquatic Plant Management 48:1-5

Laitala, K.L., T.S. Prather, D. Thill, B. Kennedy, C. Caudill. 2012. Efficacy of benthic barriers as a control measure for Eurasian watermilfoil (*Myriophyllum spicatum*). Invasive Plant Science and Management 5:170-177.

Madsen, J.D., J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, C.W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. Journal of Aquatic Plant Management. 29:94-99.

Madsen, J.D. and C.W. Boylen. 1989. Eurasian watermilfoil seed ecology from an oligotrophic and eutrophic lake. Journal of Aquatic Plant Management. 27:119-121.

Madsen, J.D. and D.H. Smith. 1997. Vegetative spread of Eurasian watermilfoil colonies. Journal of Aquatic Plant Management. 35:63-68.

Madsen, J.D. 1997. Seasonal biomass and carbohydrate allocation in a southern population of Eurasian watermilfoil. Journal of Aquatic Plant Management 35:15-21.

Martin, C.W., J.F. Valentine. 2014. Sexual and asexual reproductive strategies of invasive Eurasian milfoil (*Myriophyllum spicatum*) in estuarine environments. Hydrobiologia. 727:177-184.

Moody, M.L. and D.H. Les. 2002. Evidence of hybridity in invasive watermilfoil (*Myriophyllum*) populations. PNAS 99(23):14867-14871.

Netherland, M.D., W.R. Green, K.D. Getsinger. 1991. Endothall concentration and exposure time relationships for the control of Eurasian watermilfoil and Hydrilla. US Army Corps of Engineers Waterways Experiment Station Miscellaneous Paper A-91-4

Netherland, M.D., K.D. Getsinger. 1992. Efficacy of triclopyr on Eurasian watermilfoil: concentration and exposure time effects. Journal of Aquatic Plant Management 30:1-5.

Netherland, M.D., L.M. Glomski. 2014. Mesocosm evaluation of triclopyr on Eurasian watermilfoil and three native submersed species: The role of treatment timing and herbicide exposure. Journal of Aquatic Plant Management. 52:57-64.

Newman, R.M. 2004. Invited review biological control of Eurasian watermilfoil by aquatic insects: basic insights from an applied problem. *Arch. Hydrobiol*. 159 (2):145-184.

Newroth, P.R. 1985. A review of Eurasian water milfoil impacts and management in British Columbia. *In* L.W.J. Anderson (ed), Proceedings: 1st International Symposium on Watermilfoil (*Myriophyllum spicatum*) and related Haloragaceae species. Aquatic Plant Management Society. Washington D.C. pp. 139-153.

Olden, J., M. Tamayo. 2014. Incentivizing the public to support invasive species management: Eurasian milfoil reduces lakefront property values. PLoS ONE 9(10): e110458. doi:10.1371/journal.pone.0110458

Parks, S., R. Thum, J. Pashnick. 2014. Incorporating genetic identifications of watermilfoils into aquatic vegetation mapping to inform management decisions. The Michigan Riparian, Summer 2014: 22-25.

Parsons, J.K., K.S. Hamel, S.L. O'Neal, A.W. Moore. 2004. The impact of endothall on the aquatic plant community of Kress Lake, Washington. Journal of Aquatic Plant Management. 42:109-114.

Parsons, J.K. 2012. What's bugging watermilfoil? LakeLine 32(1):14-18.

Schulte, L.A.L., R.A. Thum. 2014. Potential for herbicide resistance evolution in hybrid watermilfoil. Abstract in program: 54th Annual Meeting of the Aquatic Plant Management Society July 2014 http://apms.org/wp/wp-content/uploads/2012/10/Final-APMS-Program-2014.pdf

Schultz, R., E. Dibble. 2012. Effects of invasive macrophytes on freshwater fish and macroinvertebrate communities: the role of invasive plant traits. Hydrobiologia. 684:1-14.

Scribailo, R.W., and M.S. Alix. 2014. Haloragaceae. Flora of North America, Provisional Publication. Flora of North America Association. 28 May 2014. http://floranorthamerica.org/node/399. Accessed 1 December 2014

SePRO Corporation. 2013a. Clearcast aquatic herbicide label. http://www.sepro.com/documents/Clearcast_Label.pdf

SePRO Corporation. 2013b. Galleon SC aquatic herbicide label. http://www.sepro.com/documents/galleon_label.pdf

Smith, C.S., J.W. Barko. 1990. Ecology of Eurasian watermilfoil. Journal of Aquatic Plant Management. 28:55-64.

Smith, D.H., J.D. Madsen, K.L. Dickson, T. L. Beitinger. 2002. Nutrient effects on autofragmentation of *Myriophyllum spicatum*. Aquatic Botany. 74(1):1-17.

Standifer, N.E., J.D. Madsen. 1997. The effect of drying period on the germination of Eurasian watermilfoil seeds. Journal of Aquatic Plant Management. 35:35-36.

Stanley, R.A. 1976. Response of Eurasian watermilfoil to subfreezing temperature. Journal of Aquatic Plant Management. 14:36-39

Tamayo, M., C.W. O'Brien, R.P. Creed, Jr., C.E. Grue, K. Hamel. 1999. Distribution and classification of aquatic weevils (Coleoptera: Curculionidae) in the genus Euhrychiopsis in Washington State. Entomological News. 110:103-112.

Thum, R.A., M.A. Heilman, P.J. Hausler, L.E. Huberty, P. Tyning, D.J. Wcisel, M.P. Zuellig, S.T. Berger, L.M. Glomski, M.D. Netherland. 2012. Field and laboratory documentation of reduced fluridone sensitivity of a hybrid watermilfoil biotype (*Myriophyllum spicatum* x *Myriophyllum sibiricum*). Journal of Aquatic Plant Management. 50:141-146.

Valent Professional Products (a). 2012. Clipper Herbicide Label.
http://www.valent.com/Data/Labels/2012-CLP-0001%20Clipper%20-%20form%201791-B.pdf

Valent Professional Products (b). 2012. Tradewind Herbicide Label.
http://www.valent.com/Data/Labels/2011-TRA-0001%20Tradewind%20%20-%20form%201796-A.pdf

Wersal, R.M., J.D. Madsen, J.H. Massey, W. Robles, J.C. Cheshier. 2010. Comparison of daytime and night-time applications of diquat and carfentrazone-ethyl for control of parrotfeather and Eurasian watermilfoil. Journal of Aquatic Plant Management 48:56-58.

Zuellig, M.P., R.A. Thum. 2012. Multiple introductions of invasive Eurasian watermilfoil and recurrent hybridization with northern watermilfoil in North America. Journal of Aquatic Plant Management. 50:1-19.