EURASIAN WATER-MILFOIL MANAGEMENT PLAN FOR SHAWNIGAN LAKE, BC

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Glossary

CVRD	Cowichan Valley Regional District
DFO	Federal Department of Fisheries and Oceans
Eutrophic	As opposed to oligotrophic, a eutrophic lake or pond has high biological productivity due to excessive nutrients, especially N and P. High eutrophication can lead to thick growth of aquatic plants or algae.
EWM	Eurasian Water-milfoil
Limnology	The scientific study of lakes
N	Nitrogen
Oligotrophic	The term used to describe aquatic environments (such as lakes) with low concentrations of nitrates, iron, phosphates, and carbon sources.
P	Phosphorous
SCOCCP	South Cowichan Official Community Plan
SBS	Shawnigan Basin Society
SLS	Shawnigan Lake School
SRA	Shawnigan Residents Association

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1 Introduction

Eurasian water-milfoil (*Myriophyllum spicatum*), an introduced invasive aquatic plant, has been identified in Shawnigan Lake. Members of the Shawnigan Residents Association (SRA), Shawnigan Basin Society (SBS) and others have become concerned about the potential impact of this species on the Shawnigan Lake ecosystem, water quality and other stakeholder values. According to the SBS, milfoil has been observed along approximately 80% of Shawnigan Lake's shoreline[1]. The SBS also noted that the plant has been established in the lake since the late 1970s, and no organized control efforts have been implemented to date.

Eurasian water-milfoil (EWM) grows rapidly, often forming densely tangled mats of vegetation near the water surface that shade out native aquatic plants. The stems break up into fragments late in summer, which disperse and propagate into new plants, allowing EWM to spread to new areas very efficiently. In addition to ecological and water quality impacts, dense growth of EWM can negatively impact recreational and aesthetic values. Eurasian milfoil spreads readily and is difficult to control, resulting in this plant being widespread in lakes and slow-moving streams across North America. The productivity and dispersal of EWM in Shawnigan Lake is influenced by numerous factors including water quality, boating and introduced fish species.

This management plan provides recommendations and a strategic framework to address the EWM problem in Shawnigan Lake, based on a review and synthesis of:

- Limnological characteristics of Shawnigan Lake;
- Ecology, impacts, and control of EWM;
- Known distribution of EWM in Shawnigan Lake; and
- EWM management measures applied in other lakes.

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[1] Shawnigan Basin Society (2018). Water-Milfoil in Shawnigan Lake, BC: http://shawniganwater.weebly.com/milfoil.html

Invasive species management can be expensive and prone to failure, and it is important to take the time to define the problem in detail, prioritize the allocation of resources, to have realistic objectives from the outset, and to update management measures and objectives based on monitoring data. Therefore, this management plan provides a starting point for controlling EWM, including recommendations for completing a baseline study, establishing monitoring sites and small-scale test-plots. This management plan will need to be updated as new data are collected, wherefrom management measures may need to adapt to objective evaluation of success and changing conditions throughout the operational life of the EWM management program. While the baseline study and experimental evaluation of management measures will take several years to complete, these tasks are relatively low cost compared to the implementation of widespread control measures – they will help to ensure the resulting long-term control effort has the intended effect. We also provide recommended interim management measures to be applied at selected priority sites starting as soon as this year.

1.1 Goals and Objectives

The overall goal of this management plan is to reduce the distribution of EWM in Shawnigan Lake; and to minimize the invasive aquatic plant's impacts on ecological and social values. Another important goal is to implement a balanced approach that maximizes results at a reasonable cost that is sustainable for the long term.

Objectives are targets for measurable parameters that serve as indicators of progress towards reaching an overarching goal. These will become better defined with the collection of additional baseline information and feedback from monitoring. For example, one objective could be to reduce the overall cover of EWM by 50% after 5 years of control effort. The cover of EWM can be measured on a regular basis so that progress can be tracked over time. As with adapting management measures as new information becomes available, objectives may need to be updated as well to ensure they are realistic (i.e. if after 5 years of control, monitoring and adaptive management, EWM has only reduced in cover by 25%, our expectations going forward may need to be adjusted).

Other example direct objectives of EWM control could be applied to EWM density (number of shoots per m^2) or biomass (kg per hectare), as measures of productivity. It may also be appropriate to set objectives related to the relative abundance and species richness of aquatic plants, invertebrates and fish, or related to water quality parameters, to provide several examples.

2 Shawnigan Lake Background

Shawnigan Lake is located within Electoral Area B of the Cowichan Valley Regional District, approximately 15km south of Duncan and 30km northwest of Victoria. The current population of the Village of Shawnigan Lake is about 3600, with about 7500 people living in Electoral Area B (2014 SCOCP). Given the close proximity to Victoria, the population is likely to continue growing.

Shawnigan Lake became a popular summer destination for Victoria residents starting in the 1890s and into the 1920s and 30s. Transportation at that time - and into the 1950s - was primarily via the E&N railway. The Cliffside and Shawnigan train stations were well-used during this time. Private vehicles became the main mode of transportation in subsequent years as the road network improved. While early visitors were mostly seasonal, permanent residents have increased considerably since the 1970s.

In recent years two community organizations have become very active in promoting public awareness and education regarding lake issues, namely the Shawnigan Residents Association and the Shawnigan Basin Society. Shawnigan Lake School, a long time user of the lake, is also involved in these matters.

2.1 Watershed Description and Hydrology[2]

Shawnigan Lake is situated at approximately 116m above sea level within a watershed covering about 69.4 km^2. Shawnigan Creek flows into the south end of the lake and out of the north end, eventually draining into Mill Bay. The main tributaries of the lake are McGee Creek, Shawnigan Creek, Roundhouse Creek, Landfill Creek, Village Creek and several un-named streams.

The lake surface area is approximately 537ha, and measures 7.2 km long and 1.4 km across at its widest point. The average depth of the lake is 12m, with a maximum depth of 52m. Shawnigan Lake's shoreline is about 28 to 30km[3]. The lake water residency time (i.e. the average time water spends in the lake) is relatively short at just under one year. Water levels are maintained by a dam on Shawnigan Creek to manage storage and prevent flooding.

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[2] The majority of information in section 3.1 is from Rieberger, K, Epps, D. and J. Wilson. 2004. Shawnigan Lake Water Quality Assessment, 1976-2004. BC Ministry of Water, Land and Air Protection.

[3] Depending on the dataset – Freshwater Atlas, CVRD Lakes, or 1989 bathymetric map

2.2 Geology of the Shawnigan Lake Basin

The lake is underlain by three geological formations[4]:

- Wark Gneiss complex (west side of the lake, and the mid portions of the east side of the lake);
- Colquitz gneiss (south-east side of the lake). Gneiss is a common metamorphic rock, forming from either igneous or sedimentary rocks. Gneiss, along with granite and quartzite, is a hard oligotrophic mineral and slow to weather (erode). It contains very little carbonate material and therefore has a low alkalinity generating capacity (Freedman, B. 1989). This likely contributes to the oligotrophic nature of portions of the lake; and
- Limestone (north end of the lake). Limestone weathering likely leads to higher alkalinity levels in some areas.

The input of minerals into a lake from bedrock will be buffered by the presence of other atmospherically and anthropogenically sourced minerals as well as water pH. The potential influence on Eurasian water-milfoil distribution in Shawnigan Lake is that areas fed by tributaries underlain by limestone could be slightly more productive (as higher pH generally results in greater nutrient availability for aquatic organisms).

2.3 Water Quality

The Village of Shawnigan Lake and surrounding area sources drinking water from the lake, which has full public-use access and much of the shoreline has been developed for residential use. A 2011 report indicates potential water quality concerns due to leaking septic systems and other activities in the watershed[5]. These concerns were primarily related to levels of fecal coliforms with a focus on drinking water quality.

More relevant to the growth of EWM, the above-noted report stated that nutrient levels in the lake continue to be low (oligotrophic), which is consistent with the findings of the Shawnigan Lake Water Quality Assessments completed in 2004 and 2007[6]. These studies agree that the productivity of Shawnigan Lake is phosphorous-limited. Therefore, if there was an increasing trend in phosphorous levels in the future, the productivity of EWM

[4] iMapBC Bedrock Geology Layer: https://maps.gov.bc.ca/ess/hm/imap4m/

[5] Mazumder (2011)

[6] Rieberger *et al*. (2004) and Rieberger (2007)

would likely increase accordingly. As such, phosphorous sampling could be a useful part of a EWM monitoring program (nutrient inputs are discussed further in Section 3.4.1). The 2004 water quality assessment concluded that there were no measured parameter levels or trends that were a cause for concern for aquatic life and recreational use.

To provide regional context, it should be noted that less than 2 km from the south end of Shawnigan Lake there is a 20,549 ha (50,776 acres) restricted access water supply area that provides drinking water to the Capital Regional District (similar to the restricted water supply areas in Nanaimo, Vancouver and other areas). Sooke Lake, within the aforementioned CRD protected watershed, is located only 4 km south-west from the southern end of Shawnigan Lake. This lake has a similar size to Shawnigan Lake, and occurs in a similar physiographic setting (geomorphology and subsurface rock types), and would be an ideal comparative "control" with regard to both water quality and ecology.

2.4 Ecological Characteristics

Riparian vegetation is typically well-developed along sections of undisturbed lakeshore. Typical shrub and tree species include Pacific crabapple, western red-cedar, black cottonwood, Pacific ninebark, red-osier dogwood, salmonberry, Douglas spirea, Sitka willow and black twinberry. Herbs and grasses include cattail, slough sedge, and manna grass. Trees, shrubs and herbs along the lakeshore provide a source of organic detritus (leaf and needle fall) and insect drop, both of which enhance the productivity of the near-shore fisheries habitat. Trees also produce shade which, from a fisheries and EWM control perspective, keeps the water cooler, and provides less light for near-shore EWM.

Various waterfowl use the lake, including many duck species. Small mammals that use the lake and tributaries include beaver, muskrat, and mink. Larger mammals such as deer, elk, bear, wolf and cougar roam the neighbouring hills and mountains.

2.4.1 Fish Species Present in Shawnigan Lake and General Habitat Requirements

Kokanee (*Oncorhynchus nerka*) are the only truly native fish in Shawnigan Lake. Salmonids that are native to the local area have been introduced over the years to the lake, and consist of rainbow trout (*Oncorhynchus mykiss*), coastal cutthroat trout (*Oncorhynchus clarki clarki*) and coho salmon (*Oncorhynchus kisutch*). Non-native introduced species that are proliferating in the lake include smallmouth bass (*Micropterus dolomieu*), yellow perch (*Perca flavescens*) and pumpkinseed fish (*Lepomis gibbosus*). Brown bullhead (*Ameiurus nebulosus*) have also been documented in the lake, but the numbers of these fish have declined significantly

(Gregory 2014). Based on this decline, no further information is provided for the brown bullhead.

The health of the native fish in the lake (the term "native" in this case applies to kokanee and also to the stocked rainbow trout and coastal cutthroat trout) reflects both a local and provincial concern for salmonids. A description for each of the known native and non-native fish species present in Shawnigan Lake is provided below. For further details regarding water temperature and dissolved oxygen tolerances for native and introduced fish species in Shawnigan Lake, as they relate to interactions with EWM, please refer to Appendix I.

Native Fish

Rainbow trout

Rainbow trout have been stocked into Shawnigan Lake since 1922 (Habitat Wizard 2018) to maintain sport-fishing opportunities. The earliest stocking records indicate that Paul and Pinantan-strain rainbow trout were introduced first, with Pennask, Knouff, Peterhope, Swalwell, Washington, Dragon, Tunkwa, Badger, Tzenzaicut and Blackwater strains also introduced over the years (Habitat Wizard 2018). Stocking records over at least the past ten years indicate that all stocked fish were (and continue to be) exclusively triploid (sterile) Fraser Valley-strain fish (Freshwater Fisheries Society BC 2018). Triploid fish are incapable of reproducing, and are used to stock lakes as they tend to grow faster and maintain condition throughout the year (these fish are not affected by the annual rigours of spawning).

Based on the temporal extent of stocking activities and numbers of fish involved - in excess of 1.7 million (Freshwater Fisheries Society BC 2018), it is extremely unlikely that any truly "native" Shawnigan Lake rainbow trout persist in the lake. It is possible that some early strains of non-triploid (diploid) fish introduced to the lake still persist as self-sustaining populations.

Any remaining rainbow trout capable of spawning would make use of higher magnitude Shawnigan Lake tributary streams, such as McGee Creek, for spawning. Shawnigan Creek (both above and below the lake) also represents potential spawning habitat.

Coastal cutthroat trout

The earliest recorded stocking date of coastal cutthroat trout in Shawnigan Lake is 1921, when Cowichan-strain fish were introduced (Habitat Wizard 2018). Compared to rainbow trout, the introduction of coastal cutthroat trout has been sporadic over the years since the first recorded release in 1921 and has involved fewer strains (Elk, Millard Creek, Corvallis, Oregon and Taylor strains). The total number of coastal cutthroat trout stocked is also less than the number of rainbow trout introduced, with approximately 478 000 fish released (Freshwater Fisheries Society BC 2018). The last recorded stocking date was in 2004, with Taylor-strain fish used exclusively for at least ten years prior to that year (Habitat Wizard 2018).

Due to the fact that coastal cutthroat trout still persist in the Shawnigan system without any current stocking initiatives indicates that self-sustaining populations exist. Despite the relative sporadic stocking activities associated with coastal cutthroat trout, the current populations are more likely to be representative of the introduced strains as opposed to representing any truly native population that may have occurred prior to stocking.

Coastal cutthroat trout likely use tributary streams such as McGee Creek and Shawnigan Creek for spawning. Smaller tributary streams to Shawnigan Creek are also likely to be used by this species.

Coho Salmon

Coho salmon are present in the Shawnigan system as a result of annual efforts to transport adult fish above the impassable waterfalls located at tidewater in Shawnigan Creek. Each autumn, adult coho salmon are captured and placed in live tanks for trucking above the sequence of waterfalls. Without this human intervention, the Shawnigan watershed would not naturally contain any anadromous fish at the current time. It is likely that prior to isostatic rebound after the last ice age, the Shawnigan watershed would have supported anadromous fish, due to the relatively higher sea level that would have occurred before the land rebounded.

Progeny from transported adult coho salmon spawning in Shawnigan Creek and its tributaries, and in Shawnigan Lake tributaries, are able to rear in freshwater and make the downstream journey as smolts over the waterfalls to the ocean. After maturing at sea, the fish return to their natal stream and are captured for transportation and release while attempting to ascend the waterfalls.

Kokanee

Kokanee represent the only truly native fish in Shawnigan Lake.This species represents a form of sockeye salmon that spends its entire life cycle in fresh water. While distinct kokanee populations are commonly found where anadromous sockeye salmon also occur, in the case of Shawnigan Lake the kokanee are a completely separate, landlocked population isolated by the waterfall barriers at tidewater. Presence of these fish indicates the historic occurrence of anadromous sockeye salmon in the system prior to isostatic rebound of the land and the associated exposure of the migration barriers at tidewater.

Mature kokanee from Shawnigan Lake likely spawn in higher magnitude lake tributary streams, as with rainbow trout and coastal cutthroat trout. Kokanee may also spawn in littoral zones around the lake. Lake spawning would be controlled by the availability of clean, well-spaced gravel, where wave action is able to maintain the supply of oxygen between interstitial spaces to developing embryos.

Introduced (non-native) Fish

Smallmouth Bass

This species is renowned as a sport fish and is very popular with anglers. This popularity has led to its unauthorized introduction into numerous lakes, especially on Vancouver Island. There is currently a popular smallmouth bass fishery on Shawnigan Lake, where the species appears to be thriving. It should be noted that the original introduction of smallmouth bass to Vancouver Island was associated with authorized releases by the Dominion of Fisheries in 1901, with fish released in Florence Lake and Langford Lake (Brown *et al.* 2009). There have been no other authorized releases of smallmouth bass anywhere else on Vancouver Island (Brown *et al.* 2009).

Littoral lake areas are important for smallmouth bass, as these zones provide both spawning and rearing habitat (Brown *et al.* 2009). Spawning occurs in relatively shallow water (1-2.5 m deep) and nest sites (small depressions excavated by male fish in the substrate) are close to cover in the form of submerged trees, boulders or dense vegetation (Moyle 2002; cited in Brown *et al.* 2009). Smallmouth bass generally have a high level of reproductive success, based on the high fecundity of females and the fact that male fish protect the eggs and fry (Scott and Crossman 1973).

Yellow Perch

This species has been introduced without authorization throughout numerous freshwater systems in southern BC. The introduction of yellow perch may be linked to unauthorized bass releases, where the intention of bass anglers may be to establish a yellow perch population for the bass to feed on (Brown *et al.* 2009). Given the popularity of smallmouth bass fishing in Shawnigan Lake, this may help to explain the occurrence of yellow perch in the lake.

Yellow perch are known to be a shallow-water species, and according to Moyle (2002; cited in Brown *et al.* 2009) are "*almost always associated with the heavy growth of aquatic plants at depths of 1-10 m*." Spawning also occurs in shallow water, where egg masses are attached to aquatic vegetation or to the substrate (Brown *et al.* 2009).

Pumpkinseed Fish

This species has become well established in many lakes throughout Vancouver Island (including Shawnigan Lake) as a result of unauthorized releases. The pumpkinseed fish is generally not considered a valuable sport fish, based on its small size, but it is popular with young anglers, as it is easy to catch and is usually found close to shore.

Pumpkinseed fish are shallow-water species and are usually found in areas consisting of abundant submerged vegetation (Scott and Crossman 1973). Spawning occurs in very shallow water (less than 1 m deep) (McPhail 2007; cited in Brown *et al.* 2009). Nests (small depressions excavated by male fish) are often associated with aquatic vegetation (Scott and Crossman 1973). As with smallmouth bass, male pumpkinseed fish protect the nests from predators (Robinson *et al*. 1993; Holtan 1998; cited in Brown *et al.* 2009), which leads to a relatively high reproductive success rate.

3 Overview and Ecology of Eurasian Water-Milfoil

3.1 General Distribution and Habitat

EWM is native to Europe, Asia and North Africa and was introduced to North America in the 1940s (Couch and Nelson 1985). It is now one of the most widely distributed invasive aquatic plants on the continent. In BC, it is found on all the larger lakes in the Okanagan valley and in numerous water bodies in the Lower Mainland (such as Cultus Lake), and on Vancouver Island. The species is most abundant in 1 – 4 m of water, but can be found in water up to 10 m deep (Aiken *et al*. 1979, cited in Smith and Barko 1990).

3.2 Taxonomy and Biology[7]

EWM is an aquatic perennial plant with slender stems up to 175 cm long that grow from rhizomes. The submerged leaves (usually between 15–35 mm long) are borne in whorls of three to five, with numerous thread-like leaflets roughly 4–12 mm long, often appearing feather-like (Pojar *et al*. 1994). Plants are monoecious (both sexes on the same plant) with

[7] Here is a description of how to distinguish it from native species: https://invasivespecies.wa.gov/priorities/invasive_milfoils.shtml

tiny orange-red wind-pollinated flowers produced in the leaf axils (male above, female below) on a elongate spike 5–15 cm held vertically above the water. The plant blooms in late July and August. The seeds are small and rounded.

3.2.1 Similar Species

Ten species of Myriophyllum are found in the Pacific Northwest (Ceska and Ceska 2010). Native milfoil species can be distinguished from EWM by the arrangement of its leaves in whorls of four around reddish stems (or green in summer). Usually EWM has 14 to 21 leaflet pairs per leaf, more than native milfoils. It may be mistaken with parrot's feather (*M. aquaticum*), which is also reported to be in Shawnigan Lake. Variable-leaf milfoil looks similar to the native western milfoil (*M. hippuroides*). See Appendix II for a key to distinguishing water milfoil species (*Myriophyllum* spp.).

EWM can hybridize with other milfoil species including northern water-milfoil (*M. sibiricum*), possibly parrot's feather, and verticillate water-milfoil (*M. verticillatum*). The resulting hybrids can be difficult to identify as the leaf characters are intermediate between the two parents. Hybrid plants can also be invasive (Moody 2007).

3.2.2 Growth Pattern

While the plant is a perennial, it has a seasonal pattern of growth. Shoots start to grow rapidly when water temperatures reach about 15 ºC. When shoots grow, lower leaves fall off as a result of shading. Shoots branch profusely when they reach the surface, forming a dense canopy above leafless vertical stems. After flowering, the plant biomass declines as a result of stem fragmentation. Variations in this pattern result from differences in climate, water clarity and rooting depth (Smith and Barko 1979).

3.2.3 Propagation and Dispersal

Vegetative reproduction by stem fragmentation and stolon formation is considered the main form of dispersal both within and between water bodies. Stem fragments are readily dispersed by water currents within lakes, and by recreational boat trailering between lakes. Stem fragmentation occurs naturally after flowering, and also occurs as a result of mechanical damage from recreational activities as well as from milfoil harvesting (Newroth 1977). Of note is that mechanical fragmentation during cold-months does not result in spread, since the dislodged fragments will not re-sprout given the cold water temperatures (below 10ºC)[8]. Fragmented EWM in water temperatures consistently less than 10ºC will decompose within a relatively short timeframe. The dispersal of seeds is considered to be of minor importance compared to fragmentation (Madsen 2013).

3.3 Ecological Factors that Influence Eurasian Water-Milfoil Growth

Compared to other aquatic plants in productive lakes, EWM is not considered to be unusually productive or reach unusually high levels of biomass (Grace and Wetzel 1978). When EWM invades relatively unproductive lakes (oligotrophic), it may out-compete less productive aquatic plant species but it does not necessarily become widespread in such lakes. As well, the species does not have a unique photosynthetic system, relative to other aquatic species (Smith and Barko 1990). Submersed aquatic macrophytes in general possess extremely low rates of net photosynthesis compared to terrestrial vegetation, and their competitive advantage over other aquatic plants is more related to their ability to elongate and form a canopy at the water surface than their productivity of biomass.

Light intensity determines many aspects of the distribution and morphology of EWM. For example, turbid water will restrict the plant to establishing in shallow rooting depths where a canopy of horizontal stems at the surface will form; likewise in clear water, EWM will have greater rooting depths (Smith and Barko 1990). However, the highly adaptive growth structure, susceptibility to mechanical disruption, spread through fragmentation, and low photosynthetic needs will enable EWM to overtop and shade potential natural or invasive competitors over a wide range of water levels and turbidity.

These notable competitive advantages can be capitalized on for management and control of EWM. For example, the low rate of photosynthesis makes this plant vulnerable to low light levels and direct shade; and the long-stems associated with deeper water colonies can be used to harvest the plants, as will be discussed in later sections.

The growth and spread of EWM is influenced by factors described in Table 1.

[8] Mossop, B. and Bradford, M.J. 2004. Review of Eurasian watermilfoil control at Cultus Lake and recommendations for future removals. Department of Fisheries and Ocean Canada.

Table 1: Factors influencing the growth and spread of Eurasian water-milfoil (Smith and Barko 1979, Alvarez 2016, Madsen 2013, Mossop and Bradford 2004).

Factor	Influence on growth
Water Clarity	• Water clarity dictates the availability of light for photosynthesis, therefore controlling the depth and rate of growth • Low water clarity (high turbidity) limits EWM to shallow water, and leads to canopy / mat formation • High water clarity allows EWM to grow at greater depths, without necessarily reaching the surface
Water Temperature	• Plants photosynthesize and grow over a broad range: 15-35C • Maximum growth occurs at fairly high water temperatures: 30-35C • Growth is initiated at about 15C • Fragments do not propagate at water temperatures below 10C
Inorganic Carbon	• Plants grow best in relatively alkaline lakes (high pH) • Plants can grow in lakes of low alkalinity (low pH), but not as vigorously
Mineral Nutrients	• Nuisance growth is primarily an issue for moderately fertile and eutrophic lakes, or fertile locations within less fertile lakes • Uptake of nutrients from sediments by roots is an important source of P and N • Major cations and bicarbonate are mostly taken from the water
Carbon Dioxide	• Gases diffuse very slowly in water, with the rate of availability limiting photosynthesis
Sediment Texture	• Plants grow best on fine-textured inorganic sediments of intermediate density (such as clay or silty clay), due to apparently greater nutrient availability
Water Movement	• Vegetative spread of plant fragments is aided by water currents • The plant does not usually occur in high energy environments (strong currents) • Water level fluctuation may limit growth
Disturbance	• Disruption of lake bottom sediments or damage to existing vegetation will create 'gaps' in which the opportunistic EWM will take root.

Healthy aquatic ecosystems are typically resilient to infestation by noxious weeds. However, disturbances and the other factors listed above collectively determine how readily EWM will invade new habitat.

3.4 Human Factors that Influence Eurasian Water-Milfoil Growth

Some ongoing land use impacts or stressors may be contributing to the growth and dispersal of EWM in Shawnigan Lake, to varying extents. Human impacts can be summarized as follows:

- Nutrient inputs originating from septic systems and fertilizer;
- Motorized recreation on the lake;
- Removal of riparian vegetation and large shade producing trees to create lawns and beach areas;

- Mechanical fragmentation of plants (plant fragments are the principal means of EWM propagation); and
- Introduction of non-native fish.

3.4.1 Nutrient inputs

Human induced nutrient input is primarily the result of leaking septic infrastructure, application of fertilizer to ornamental planting (e.g. grass, flowers, shrubbery etc.), agricultural fields, or pasture. Typically the input of nutrients will encourage vegetation growth not only near the point of entry, but also in locations known to have suppressed water turnover (e.g. deeper parts of the lake). However, due to Shawnigan Lake having the relatively short water residence time of 1 year, accumulation of nutrients within the more stagnant water will not reach particularly high concentrations.

3.4.1.1 Nitrogen

It is our understanding that nitrogen levels in Shawnigan Lake are generally low (Rieberger *et al.* 2004), and nitrogen is not a limiting nutrient for the lake's productivity. However, it is worth noting the potential impacts of nitrogen loading in lakes.

Nitrogen is an omnipresent substance as it naturally exists in water (aqueous phase), soil (solid phase) and in the air (gaseous phase). Furthermore, the nitrogen cycle ensures a steady exchange between the three — e.g. Earth's atmosphere is mostly nitrogen — and nitrogen in the air can dissolve into the water of the lake. Some species of algae are able to take this form of nitrogen out of the water. If the flow of nitrogen is cut off, the community of species making up algae blooms — consisting of hundreds of species — will shift toward those species that can use the form of nitrogen from the air, resulting in a consistent biomass of algae in the lake. Stagnation of water turnover and significant increase of nitrogen conenctration within the water would lead to a generally increased vegetation growth.

There have been a number of studies looking at controlling aquatic plant growth by controlling the amount of nitrogen and phosphorous going into lakes. Most of these studies have focused on toxic algae and results have been mixed. For example, scientists working in the Experimental Lakes Area in northwestern Ontario conducted a whole-ecosystem experiment on one lake, beginning in 1969. They examined the roles of the nutrients carbon, phosphorus and nitrogen in controlling algae blooms. Likewise, efforts to reduce toxic algae blooms on Lake Winnipeg by controlling the amount of nitrogen flowing into the water had little to no impact. In 1990, the researchers completely cut off the flow of nitrogen while maintaining the artificial flow of phosphorus into the lake. They found that nearly 25 years after the flow of nitrogen had been cut off, the size and duration of the blooms on the lake remained largely unchanged.[10]

3.4.1.2 Phosphorous

Productivity in Shawnigan Lake is primarily phosphorous-limited (Rieberger *et al.* 2004). Thus, phosphorous loading would result in greater changes to the lake ecosystem than nitrogen loading.

Phosphorus, on the other hand, is primarily found in soil as the major source of mineral or complexed solid phase and in water as a minor source of aqueous phase. If the amount of phosphorous that comes in through rivers and overland is reduced, the plants cannot get this nutrient from elsewhere as there is no mechanism for cycling phosphorous throughout the environment that operates on a short timeframe. Therefore, reducing phosphorus may be more effective.[9]

Effective erosion and sediment control measures applied to developments and ongoing land uses in the watershed with the potential to introduce sediment into the lake are an important aspect of phosphorous loading prevention.

3.4.1.3 Older Septic Systems

Many older septic systems are within 10m of the lake natural boundary and, if those systems are functionally compromised due to age, would allow septic outflow to enter the groundwater or the lake with minimal attenuation. The transport of nutrients through septic systems to the lake, coupled with the solubility of primary nutrients (nitrogen and to a considerably lesser degree phosphorus) will result in proximal and widespread increase in microbial and plant available nutrients.

3.4.1.4 Fertilizer Leaching and Livestock

Typically, natural and synthetic plant fertilizers are the mineral forms of nutrients which are directly accessible by plants so as to ensure rapid uptake for intentional application scenarios. However, secondary exposure occurs through over-application (i.e. not all nutrients are taken up by the intended target vegetation), and subsequent leaching by precipitation or irrigation water. Sources can be residential, institutional, agricultural, and forestry-related.

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[9] Biological Nitrogen Fixation Prevents the Response of a Eutrophic Lake to Reduced Loading of Nitrogen: Evidence from a 46-Year Whole-Lake Experiment. https://rd.springer.com/article/10.1007%2Fs10021-017-0204-2

Lawn grasses do not typically absorb all of the fertilizer applied, even when using 'delayed' or 'long-lasting release' encapsulated mineral synthetic fertilizers. This results in nitrogen leaching which can vary from less than 1% to 71 % of that applied (Barton and Colmer 2005). For trees and shrubs, fertilization is often seen as a substitute for natural nutrient cycling that is disrupted by the removal of leaves and twigs in landscapes. However, fertilization of trees and shrubs at standard recommended rates (which are typically much higher than the amount of nitrogen in fallen litter (Larcher 1975) may be ineffective if soil fertility is moderate or good (Watson and Hewitt 2017), which is likely the case for the mature forest soils close to Shawnigan Lake. The excess nitrogen (not absorbed by plants) is then available for leaching.

There are no large farms abutting the lake; however, there are a number of farms on lower Shawnigan Creek and elsewhere within the watershed that would transport the highly soluble fertilizers or nutrients from animal husbandry practices to Shawnigan Lake. Other low-density animal manure sources, such as small-scale cattle, poultry, pigs and recreational horse farms are present on various properties close to the lake.

3.4.1.5 Forestry

Felling of trees can result in increased decomposition of stumps, forest humus and litter, and the organic fraction of the soil. Mobilization of nutrients, particularly nitrate, from this decomposition could leach to ground and surface water flowing into Shawnigan Lake. Mitigation of this process is accomplished through prompt re-planting soon after felling. Increased erosion due to a loss of canopy intercept and root reinforcement as a consequence of logging can also result in sediment transport into Shawnigan Lake.

3.4.2 Impact of Motorized Recreational Watercraft

The impacts of motorized watercraft are summarized here, and then discussed further in this section:

- Transport of plant fragments by boats from lake to lake;
- Fragmentation of plant parts within the lake, particularly in shallow areas;
- Turbidity;
- Wave turbulence in nearshore environments; and
- Wave turbulence on lakeshores.

Shawnigan Lake has been very popular for boating for many years, with activities such as water skiing, wake boarding, and other pastimes, which are enhanced by having large wakes, being popular. The wake of motorized watercraft is capable of churning up lake bottom sediments in shallow areas and causing localized bank erosion. This action contributes to general turbidity from suspended sediment, in addition to re-suspending nutrients such as phosphorus that has originated in plant and animal material, and become contained in the sediment in the lake bottom (Wetzel, 2001). The suspended sediment decreases water clarity (i.e. increased turbidity) due to the additional particles suspended in the water column (UK Marine SAC 2018). Actively growing EWM and algae are able to access the re-suspended nutrients, resulting in increased growth. However, EWM is less likely to become established in turbid water due to reduced light.

3.4.3 Potential Impacts of EWM – Non-Native Fish – Native Fish Interactions

Negative impacts to native fish populations resulting from the introduction of non-native fish species into Shawnigan Lake are likely compounded by the EWM infestation. Based on preferred habitats, life-history traits (see Section 2.4.1), and the water temperature/dissolved oxygen tolerances of non-native introduced fish in Shawnigan Lake (see Appendix I), it is reasonable to assume that EWM proliferation would have little effect on these (non native) fish. EWM may actually increase the suitability of Shawnigan Lake for non-native introduced fish. The reasoning for this is that all of the introduced non-native fish actually require shallow, weedy lake areas to complete essential life history stages (*e.g.* spawning), where EWM is most prolific (see Section 3.4.3.4).

3.4.3.1 Weedy Habitat Use in Littoral Zones

While salmonids will also use weedy habitat in near-shore littoral zones for foraging, given the abundance of prey items, it is likely that benefits of EWM to non-native introduced fish would outweigh any benefits to native fish. Non-native fish such as smallmouth bass will use heavily weeded areas for hunting, and pumpkinseed fish will also use weedy shallows for cover to avoid predators. Yellow perch are known to use aquatic vegetation as an attachment medium for egg masses during the spawning period. Nest sites of smallmouth bass and pumpkinseed fish are also generally associated with aquatic vegetation. The occurrence and continued proliferation of EWM is likely, therefore, to increase the availability of predatory opportunities and spawning habitat for these species.

3.4.3.2 Water Quality Tolerances

Shallow littoral zones supporting EWM may actually be inaccessible during certain times of the year for salmonids (*i.e.* summer time), based on water temperature, or only tolerated during short periods of time for feeding activity (*e.g.* early mornings and/or late evenings). Non-native introduced fish would not necessarily be forced out of shallow lake areas in this way during periods of higher water temperature, based on an increased tolerance (and preference in some cases) for higher water temperatures. Non-native fish are also better equipped to deal with any seasonal decreases in dissolved oxygen that may occur in shallow lake areas as a result of annual EWM die-off. Continued EWM spread may also decrease the availability and quality of spawning habitat for any lake-spawning kokanee by "smothering" potentially-available substrate.

3.4.3.3 Piscivorous Predator – Prey Dynamics

Due to the fact that EWM is unlikely to be a negative factor to non-native introduced fish and actually appears to benefit the life-history traits of these fish in comparison to salmonids, it is important to consider competition for resources. For example, at the juvenile phase, yellow perch, pumpkinseed fish and smallmouth bass consume zooplankton and aquatic insects, with pumpkinseed fish continuing to feed on these items at maturity (Gregory 2014). This feeding preference leads to direct competition and a potential decrease in available food for native kokanee in Shawnigan Lake, as kokanee feed on the same elements (Gregory 2014).

Smallmouth bass, especially at maturity, are highly piscivorous, and will consume salmonids as well as yellow perch, pumpkinseed fish and juvenile smallmouth bass. Due to this predation on other species, once established in a system, smallmouth bass tend to dominate (Brown *et al.* 2009). The fact that smallmouth bass are well established in Shawnigan Lake has likely led to a reduction in salmonid populations in the lake (Gregory 2014).

3.4.3.4 Eurasian Water-Milfoil – Crayfish – Smallmouth Bass Relationship

An interesting dynamic may occur between smallmouth bass, native signal crayfish (*Pacifastacus leniusculus*) and aquatic vegetation in Shawnigan Lake. Crayfish represent a very important prey species for smallmouth bass once the fish grows to a length greater than 50 mm; beyond a length of 100-150 mm, crayfish and fish dominate the diet of smallmouth bass (Moyle 2002; cited in Brown *et al.* 2009). Studies on smallmouth bass in the Snake River revealed that 86% of the diet (by weight) of adult smallmouth bass consisted of crayfish (Keating 1970; cited in Brown *et al.* 2009). Similar studies in the Columbia River also revealed that crayfish were the main food item (72% of the total diet) (Bennett *et al.* 1991; cited in Brown *et al.* 2009). It is reasonable to assume that crayfish are similarly targeted as one of the primary (if not dominant) food items in Shawnigan Lake.

The tendency of smallmouth bass to consume crayfish as a dominant prey item is notable based on the fact that crayfish consume attached algae (periphyton) and aquatic plants, which presumably includes EWM. As per Gregory (2014), long-term Shawnigan Lake residents have suggested a decrease in the number of crayfish in the lake and an increase in periphyton (no data are available to support this observation). Gregory (2014) further suggests that the drop in crayfish numbers and apparent increase in periphyton coverage may be attributable to predation of crayfish by smallmouth bass. It is reasonable to suspect that the proliferation of EWM (in addition to periphyton) may be affected, at least in part, by the predator-prey relationship between smallmouth bass and crayfish.

Studies by Maezo *et al.* (2010) are worth noting with regard to crayfish population densities and the occurrence of EWM. Observations of the interactions of rusty crayfish (*Orconectes rusticus*) and EWM (both invasive species) in Quebec by Maezo *et al.* (2010) indicated that at certain population levels, rusty crayfish can actually encourage the proliferation of EWM, through the dispersal of clipped plant fragments. It was shown that any positive effects from EWM consumption by the crayfish were negated by an increase in the dispersal of plant fragments, but only at low to intermediate crayfish population densities. Where crayfish numbers were higher, however, consumption and/or destruction of the plant outweighed any benefits to the plant associated with dispersal, and proliferation of the plant was actually inhibited.

Based on the feeding preferences of smallmouth bass, it is extremely likely that the crayfish population in Shawnigan Lake has been reduced since the introduction of these fish. It is possible that the decrease in crayfish numbers has reached the point where dispersal of EWM by crayfish from fragmentation (milfoil proliferation) is exceeding any benefits from direct consumption/destruction (milfoil inhibition). In other words, in a lower than normal crayfish population scenario (resulting from smallmouth bass predation), crayfish may actually be helping to spread EWM through the dispersal of fragmented plants.

3.4.3.5 Implications of Ecosystem Dynamics

As part of a long-term EWM management plan in Shawnigan Lake, it may be worth exploring in more detail the relationship between smallmouth bass predation on crayfish and aquatic vegetation growth. The key would be to determine whether native crayfish represent a significant consumer of EWM in the lake. Studies related to signal crayfish in Britain (where this species of crayfish is invasive) indicate that crayfish grazing can substantially reduce the coverage of macrophytes, even to the detriment of native British species (Flint and Goldman 1975; Chambers *et al.* 1990; cited in Moorhouse and MacDonald 2015). Studies carried out in Sweden by Nystrom and Strand (1996) to determine potential impacts of signal crayfish (invasive in that particular study) on native aquatic species revealed that signal crayfish are capable of significantly decreasing both the cover and diversity of macrophytes. It is likely, therefore, that EWM is being consumed and/or fragmented by signal crayfish in Shawnigan Lake; the main question would be related to the magnitude of the consumption/fragmentation.

The studies by Maezo *et al.* (2010), albeit associated with a different species of crayfish, seem to support at least a potential linkage between crayfish population densities and EWM growth in Shawnigan Lake. It is possible that if the smallmouth bass population could be eradicated, or at least decreased in Shawnigan Lake, then an increase in crayfish densities may tip the balance in favour of EWM inhibition through direct consumption/destruction as opposed to dispersal. While an increase in the crayfish population would not necessarily rid the lake of EWM, it would represent an additional control measure, and also help to ensure that the situation is not being made worse by an artificially low-density crayfish population aiding the spread of the plant.

There may be other potential unexplored interactions between introduced fish species and the ecology of Shawnigan Lake. Some of these interactions may be directly or indirectly related to the proliferation of EWM.

The removal of EWM is not expected to have any adverse impacts on salmonids in Shawnigan Lake, as long as removal operations are completed in an appropriate manner during an optimal time of the year. Any potential negative changes in habitat availability or specific habitat attributes are likely to affect non-native introduced species of fish.

3.4.4 Disturbance to Riparian Vegetation

Riparian areas represent the transitional zone between upland areas and aquatic habitat, which are important for the maintenance of water quality. Degraded riparian areas are those where riparian vegetation is lacking, which can result in:

- Less shading of the water, which can increase water temperature and potentially result in lower levels of dissolved oxygen (cool water holds more dissolved oxygen than warm water);
- Less litter input into the water (food for the invertebrates that salmonids consume);
- Less filtering capacity to control nutrient leaching, contaminants, and sediment;
- Greater likelihood of invasive species such as EWM; and
- Lack of water movement resulting from clogged waterways leading to high water temperatures and less dissolved oxygen in the water.

4 Impacts of Eurasian Water-Milfoil

The impacts of EWM are well documented (Madsen 2013, Alvarez 2016, Smith and Barko 1979). When well-established, EWM can form dense underwater mats that shade other aquatic plants, and when the foliage of large stands begin to die off in the fall, the decaying plants can reduce oxygen levels in the water. These and other impacts are listed below:

- EWM can crowd out established native plants due to the rapid spread of EWM into lakes, areas with slow moving water, and locations where native aquatic plants are not well established;
- Dense mats can interfere with recreational activity, and can be dangerous for swimmers if they become entangled in dense patches;
- Dense growth can also create stratified water columns where the lower layer is a low oxygen zone. EWM accomplishes this by decreasing the sunlight available for native aquatic vegetation and inhibiting photosynthesis, which normally increases dissolved oxygen;
- EWM can impact oxygen absorption by preventing the wind from mixing the oxygenated surface waters with deeper water (Alvarez 2016);
- Plant fragments and larger mats may be unattractive to beach users, decreasing beach and facility usage;
- Dense EWM growth can have a negative impact on fisheries by creating microhabitats for juvenile fish and obstructing space for larger fish and disrupting their normal feeding patterns;
- The plant does not provide the same microhabitat for invertebrates compared to native aquatic plant species, thus densely populated areas of EWM can create an ecosystem with fewer prey items for surrounding fish;
- EWM can create habitat for certain mosquitos due to the water-calming effect, sheltering larvae from predators and creating inhospitable conditions for predators (not verified in the case of Shawnigan Lake);
- Reductions in property values in areas of severe EWM infestations; and
- EWM can clog water intakes.

5 Control of EWM

5.1 General Principles of Invasive Plant Management

Invasive plant management will differ according to the plant being controlled, the geographical location, regulatory environment, and social concerns. However, the following principles apply to most invasive plant management plans:

- Proper identification and knowledge of the plant;
- Inventory, mapping, and monitoring of weed populations;
- Establishing methods that would convert the problem plant into a resource, such as organic matter composting;
- Assessing the cost of control method(s), and potential impacts to other resources;
- Evaluating the effectiveness of the interventions;
- Controlling the plant from areas of least density to areas of greatest density;
- Determining the most optimum time to apply control methods, by knowing at which point in its life cycle the plant is most vulnerable. For many plants the point of vulnerability is when its carbon reserves are lowest – which is often at the time of flowering or seed-set. EWM is also very vulnerable to low light levels – being an aquatic plant it grows in a low light environment (water), so any additional shade will hinder photosynthesis and plant growth; and
- Disposing harvested plant material appropriately by transporting to a suitable composting facility or providing it to local farmers as a fertilizer resource.

Achieving control of a species is a more realistic goal than total eradication. This is also the objective of integrated pest management (IPM). IPM aims to suppress pests (in this case weeds) below the economic injury level. The UN Food and Agriculture Organisation defines IPM as "the careful consideration of all available (weed) control techniques and subsequent integration of appropriate measures that discourage the development of weed populations and keep interventions to levels that are economically justified and reduce or minimize risks to human health and the environment" (www.fao.org, Accessed Jan 26, 2018).

Management of invasive plants can be multi-faceted. At times it can be as simple as pulling an undesirable plant out of the ground, but more often the management strategy will be based on the biology of the plant, available personnel and resources, access, management unit, public visibility, risk of spread, degree of impact on adjacent areas (or plants), local knowledge, and disposal issues. In some situations, an invasive plant may even have some usefulness. In this case, control rather than eradication is a more realistic strategy. Restoration Ecologist David Polster strongly supports a strategy of ecosystem rehabilitation that seeks to create a resilient ecosystem that is able to defend itself once invasives are removed. However, for complete and enduring success, the source of invasives must be controlled and the ecosystem monitored (Polster 2002).

Specific EWM control methods are described in the following section. The integration of two or more complimentary control methods will likely deliver the best result, and the most effective combination and application of management measures will be determined through monitoring and experimental design (see Sections 7.2 and 7.3).

5.2 Summary of Control Methods

Eradication of EWM is an unrealistic goal; however, control is possible with sufficient community support. Control means minimizing the distribution of EWM and maintaining it at a level based on what is acceptable and feasible. Funding would ideally cover a number of years if control efforts are to be successful – sporadic attemps may be ineffective and not cost effective. Control options for EWM can be summarized into three general categories:

1. **Physical:** manual or machine removal of the plants, or the installation of benthic barriers to block sunlight during a critical portion of the growing season
2. **Chemical:** using herbicides or other chemicals to kill the plant
3. **Biological:** using insects, fish or other organisms to control the plant (such as milfoil weevil, pathogenic fungus, or crayfish). These approaches are promising; however, all biological control approaches must be carefully considered due to inherent challenges and unforeseen impacts.

5.2.1 Timing of Control Methods

The ideal time to intervene using any one of the various control methods is highly dependent on the approach. For example, the best timing for chemical control is just prior to flowering, when carbon storage in the plant is at its lowest and plant resilience is low. However, similar timing using physical mechanical harvest would result in fragmentation and colonization of other areas. Practically speaking, if personnel and resources are available, the plant can be harvested at any other time during the growing season, keeping in mind the primary method of spread and taking appropriate precautions.

5.3 Physical

Physical removal is the mechanical, manual removal of plants, and plant barriers. Manual removal can consist of private property owners clearing EWM from lake shore areas, or divers removing the entire plant as well as the roots.

5.3.1 Manual removal

Hand-harvesting of invasive milfoils has had some success. For example, several organizations in the New England states have undertaken large scale, lake-wide hand-harvesting management programs with extremely successful results (Upper Saranac Foundation). However, once the plant has become established, total eradication is deemed to be unlikely. In this case, controlling the spread and size of colonies is the objective and ongoing removal must be carried out once an infestation has been reduced to affordably controlled levels.

5.3.2 Manual Removal by Divers

Well-trained divers with proper techniques have been able to effectively control and maintain many lakes, (for example in the Adirondack Park in Northern New York) where chemicals, mechanical harvesters, and other disruptive and largely unsuccessful management techniques are banned. The two main diving techniques are: (1) suction dredge harvesting, where the plants are uprooted by hand by the diver, making sure to remove as much of the root as possible, and then fed into a suction hose, and (2) hand-pulling in areas where there are fewer plants, and the diver pulls the plants and puts them in a mesh bag. After only three years of hand harvesting in Saranac Lake, the program was able to reduce the amount harvested from over 18 tons to just 800 pounds per year (Upper Saranac Foundation). Diver-operated suction dredges in BC have had good results but were found to be cost-effective only in areas of small new infestations and around docks and water intakes (Newroth 1979).

5.3.3 Mechanical Harvesting

Mechanical harvesting involves a machine that cuts the plant at a certain depth below the water's surface (e.g. 1.5m) and bundles the plant material for removal and transport. In BC, the first EWM removal tests were done with an Aquamarine harvester in 1972. EWM control was initially ineffective and actually tended to encourage further spread through plant fragmentation (Newroth 1979). Since harvesting only works during the growing season when much of the plant mass is within reach of the harvester, this method will inevitably spread plant propagules and potentially expand the infestation. Therefore, harvesting should only be considered where the infestation is widespread (all or most of the potential EWM habitat has been colonized).

5.3.4 Rototilling[10]

Rototilling cuts the plant roots to a depth of 20 to 25cm below the lake bottom. After rototilling, it usually takes EWM 1 to 2 years to recolonize treated areas. It is an efficient way to treat large infestations.

Rototilling EWM should only be considered during dormant cold-weather months, where the water temperature is anticipated to remain below 10°C for a period of two-weeks post-treatment. This prolonged temperature requirement is to ensure that re-sprouting of loose fragments does not occur and that active biologic decomposition of the fragments will take place.

The dredging of EWM has also had some success, however it results in considerable disturbance to the lake bottom, a disturbance which is likely advantageous to EWM (Smith and Barko 1990). In the case of Shawnigan Lake it would also require a permit under the Provincial Water Sustainability Act.

5.3.5 Dispersal Barriers

Floating barriers have been used in Okanagan Lake to control the spread of EWM since fragmentation, winds, wave, and boats tend to disperse buoyant and viable plant segments. Barriers have also been deployed around harvesters and rotovators to control the plant fragments the machines produce. Barriers have been tested in lake channels to prevent the downstream spread of the plant (Madsen 2013).

5.3.6 Benthic Barriers (Shading)[11]

Benthic barriers cover the lake bottom and block sunlight, which prevents the growth of EWM. Sheets of woven geotextile or landscape fabric are anchored on the lake bottom to shade out EWM during the growing season. They are suitable for controlling EWM in

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[10] From Mossop and Bradford (2004)

[11] Efficacy of Benthic Barriers as a Control Measure for Eurasian Watermilfoil (2017)- https://www.cambridge.org/core/journals/invasive-plant-science-and-management/article/efficacy-of-benthic-barriers-as-a-control-measure-for-eurasian-watermilfoil-myriophyllum-spicatum/A065DEC89EA03F4599DD8E89384A74BD

AND Managing Milfoil with Bottom Barriers Factsheet - http://www.cayugacounty.us/portals/0/wqma/weedswatchout/documents/benthicbarriermilfoil.pdf swimming areas, around docks and boat launches – relatively small priority areas. Benthic barriers should be installed in the spring, before May, and left in place for 8-10 weeks. After 8-10 weeks the barrier should be removed to allow for the recovery of native aquatic plants. This is preferable to leaving benthic barriers in place year-round, which can also be an effective measure; however, by removing them after 8-10 weeks, native aquatic plants are able to rebound during the remainder of the growing season. Moreover, permanent benthic barriers require annual maintenance to clean off accumulated sediment and any plants that found a way through the barrier.

5.4 Chemical

Various herbicides have been used to control EWM including Diquat[12], Paraquat and 2, 4-D (Aqua-Kleen 20). In the tests done in 1977 on Okanagan Lake, 2, 4 D was shown to be effective in killing the EWM roots in most treatments (Newroth 1979). The main factors affecting the success of the treatments included weather conditions, time of year, water depth, the configuration and density of the target vegetation and the uniformity of the application of granules. However these tests were discontinued in 1978 due to public pressure over the use of 2, 4-D in Okanagan Lake. Considering that Shawnigan Lake provides drinking water to the Village of Shawnigan Lake and surrounding areas, chemical means of controlling EWM will not be discussed further in this report.

5.5 Biological

Biological control is the use of insects or animals to control the plant. Species used include milfoil weevil and pathogenic fungus. These approaches are promising but come with other challenges, including costs, which would be fully explored in any future version of this management plan.

5.5.1 Reduction and Control of Introduced Fish Populations

Though not typically thought of as biological control, as in releasing a new controlling species into the environment, the reduction and control of non-native fish in Shawnigan Lake could contribute to desirable outcomes for both EWM management and native fish populations. In particular, the expected result of reducing the population of smallmouth bass in the lake is an increase in crayfish population leading to increased herbivory of

[12] Description of Diquat characteristics: http://pmep.cce.cornell.edu/profiles/extoxnet/dienochlor-glyphosate/diquat-ext.html

EWM. This could be a key factor influencing the level of success of integrated control methods. The reduction of the smallmouth bass population in the lake could be achieved through collaboration with recreational fishers.

6 Eurasian Water-Milfoil in Shawnigan Lake

The known distribution of EWM in Shawnigan Lake is shown in Figure 1, along with habitat suitability zones (areas of potential EWM colonization). The known distribution shown is from a presence / absence survey completed over a seven hour period on September 21st 2015, by Mar Martinez and Kelley Musselwhite[13]. This survey provides a basic snapshot of EWM distribution throughout the lake, generally illustrating that the plant has become fairly widespread along the lakeshore. The actual areal coverage in hectares has yet to be determined; the spatial extent of the infestation has not been mapped.

Habitat suitability or areas of potential colonization were mapped based on existing bathymetry; areas of the lake with depths ranging from 1m to 4m have a high potential of EWM colonization, and depths from 4m to 10m have a moderate potential of EWM establishment. Lake fringe areas with depths less than 1m have a low potential to support EWM, due to the effects of wave action. Areas of the lake deeper than 10m have a low potential to support EWM, due to the lack of sunlight transmission and lower water temperatures.

Table 2: Areas of potential EWM colonization by depth zone in Shawnigan Lake.

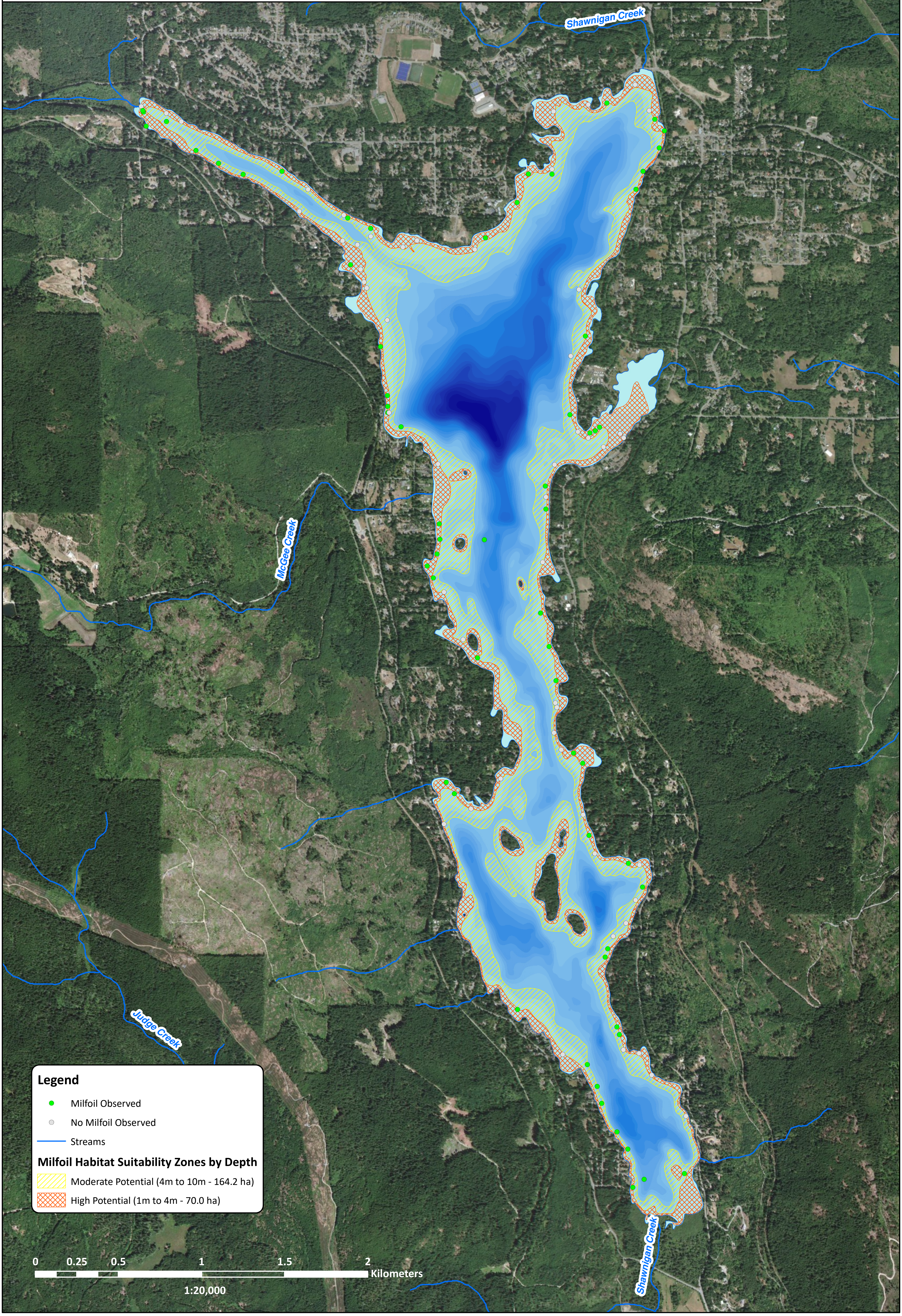
Potential for Milfoil Colonization (Water Depth)	None to Low (<1m or >10m)	Moderate (4m to 10m)	High (1m to 4m)
Area within Shawnigan Lake (hectares)	337.9	164.2	70.0

Approximatley 70 hectares (13%) of Shawnigan Lake is represented by the 1m to 4m depth zone, which is at highest risk of EWM invasion. Depths from 4m to 10m cover about 164 hectares (31%), which are at moderate risk of EWM colonization.

[13] See "Boat Survey" results: https://farwestgeo.maps.arcgis.com/apps/MapSeries/index.html?appid=18637ddd620d4ac18f2df6fb3f7d1076&folderid=2c563b2bb3164db0b105803a0a8ff526

MADRONE environmental services ltd.	PROJECT: Eurasian Milfoil Management Plan for Shawnigan Lake, BC	LOCATION: Cowichan Valley Regional District	DOSSIER: 18.0020	N
	CLIENT: Shawnigan Lake School	MAP DATE: February 28, 2018	DRAWN BY: Ian Wright, PAg., RBTech., ADGIS	

Eurasian Water-Milfoil Known Occurrences and Habitat Suitability by Depth



7 Discussion and Recommendations

7.1 Interim Management for Priority Areas

Widespread management of EWM in Shawnigan Lake should not be implemented in the short term – that should follow the results of a baseline study and evaluation of monitoring sites and test plots. Completing these initial steps will inform a more effective EWM long-term management effort.

In the meantime, some priority areas may require immediate attention to maintain recreational values. Priority areas may include areas around docks, boat ramps and designated swimming areas such as Mason's Beach. Priority areas to treat in the short-term could be identified through a participatory mapping workshop with interested community members.

Based on the review and synthesis of control techniques for EWM, we recommend that these priority areas be treated with the use of one or a combination of two low-risk techniques:

1. install temporary benthic barriers / bottom covers early in the growing season; and
2. hand removal by a SCUBA diver.

7.1.1 Benthic Barriers

Benthic barriers cover the lake bottom and block sunlight, which prevents the growth of EWM. They are suitable for controlling EWM in swimming areas, around docks and boat launches. Benthic barriers should be installed in the spring, before May, and left in place for 8-10 weeks. After 8-10 weeks the barrier should be removed to allow for the recovery of native aquatic plants. Please see Section 5.3.6 for further details. Benthic barriers are potentially the most appropriate and effective interim management measures for selected priority areas.

7.1.2 Manual Removal by Divers

Hand removal of the plant by a SCUBA diver can be implemented in priority areas, keeping in mind that the main mechanism of EWM dispersal is by fragmentation – small pieces of the plant have the potential to take root and sprout into new plants if they settle on suitable lake bottom habitat. The range of suitable habitat for EWM is wide and EWM's potential to colonize new areas in the lake is high. It is important, therefore, that as much of the harvested plant material as possible is recovered from the lake.

Timing is also of critical importance, in that later in the growing season when the EWM shoots reach the surface of the water and begin to flower, the plant becomes prone to fragmenting and dispersing. Mechanical removal techniques applied at the wrong time could cause EWM to spread to new areas of the lake. Removal should be completed early in the summer before the plant shoots reach the flowering stage, while the stems still hold together well. The plants should not be disturbed once they are flowering and thereafter, to prevent unintentionally contributing to its fragmentation and dispersal. Please refer to Section 5.3.2 for further details.

7.1.3 Integrated Approach

The most effective interim management method would be the integration of the techniques described previously:

1. Install benthic barriers in late April;
2. Remove EWM shoots that have grown through the barriers and around their edges in late May;
3. Remove the benthic barriers in late June to early July (8-10 weeks later); and
4. Remove remaining EWM shoots prior to flowering

7.2 Baseline Study and Monitoring Plan

The development of an effective EWM management strategy should follow an adaptive process beginning with a baseline assessment, followed by implementing management measures, monitoring the effect of those measures, and adapting the approach, as necessary. A baseline study and monitoring plan provide the foundation for tracking progress towards achieving the goals and objectives, and to make sound management decisions.

A baseline study will provide a more detailed understanding of the extent of the EWM problem in Shawnigan Lake. At a minimum, the distribution and density of the infestations should be assessed and mapped, building upon the presence/absence survey completed in 2015. Permanent monitoring sites and transects should be established after the aerial extent of EWM has been mapped. Monitoring sites should include areas where the infestation is most severe, areas of low to moderate EWM density, as well as areas where there is currently no EWM that could potentially be invaded. These permanent monitoring sites and transects will provide for repeatable surveys to quantify EWM distribution and other related indicator data (Table 3).

Table 3: Recommended Parameters for a Baseline Study and Monitoring Eurasian water-milfoil Management in Shawnigan Lake

Parameter Description	Key Questions	Application to EWM Management	Methodology Comments
EWM Distribution Extent of coverage	• What is the full extent of the EWM infestation – where is it and how much area does it cover? • Of the potential EWM habitat (depths of 1m to 10m), what percentage of that area has already been colonized? • How does the EWM distribution change from year to year?	• This is the most direct measure of the success of EWM management, as a reduction in EWM cover is the primary objective (prioritized areas and targets for % reduction to be determined). • If the reduction target for EWM cover is not met, management methods may need to be adapted, expectations may need to be adjusted, or both.	• The outer edge of EWM patches can be mapped by a snorkeler or diver accompanied by a support boat – the snorkeler or diver identifying the edge and the support boat marking the edge using a differential GPS unit (for high accuracy). • Distribution of EWM rooted in the shallow to mid depths could be mapped using an unmanned aerial vehicle (UAV) while the plant is in flower and has grown above the water's surface. Visibility may be a barrier for this method to apply to deeper-rooted EWM patches that do not reach the water's surface
EWM Density # of shoots / m^2	• Where is EWM most and least productive? • How does EWM density relate to other monitoring parameters?	• Prioritize management efforts in areas where EWM is least productive (attack it where it's weakest). • This is a direct measure of the success of EWM management, as a reduction in EWM density indicates a reduction in productivity and biomass – a direct weakening of the infestation.	• Count the number of shoots within a $0.25m^2$ quadrat placed at regular intervals along permanent monitoring transects, set up at each monitoring site or test plot. • Density samples are averaged for each plot.
Depth tolerance of EWM in Shawnigan Lake Lake depth of EWM (min, max, mean)	• What depth range is EWM found in the lake, and what is the average?	• This can be used to further refine the mapping of areas that may be vulnerable to invasion, and to prioritize removal efforts (newly colonized areas within the average depth zone would be a higher priority for control as those areas are more susceptible to dense EWM growth).	• Can be done with a measuring tape with a weight on the end, by divers or dive tenders. • Depth should be recorded at each quadrat location along the permanent monitoring transects – this only needs to be done once.

Parameter Description	Key Questions	Application to EWM Management	Methodology Comments
Water Quality Temperature Turbidity DO Conductivity pH	• Are there any significant differences between monitoring sites? • Do some sites have more favourable water quality for EWM growth than others? • Is there any improvement in water quality after EWM removal?	• This could improve the prioritization of treatments – to first direct control efforts to areas where EWM is least productive, to attack it where it's weakest (i.e. lower temperature, higher turbidity, lower nutrients).	• These can be simple spot samples taken in conjunction with EWM cover and density monitoring, as well as water quality loggers left year-round to collect a continuous dataset (temperature loggers are relatively inexpensive, and turbidity loggers are also available). • It is beneficial that a considerable amount of historical water quality data is available for Shawnigan Lake, as it provides an existing baseline to compare to.
Substrate (lake bottom sediments)	• In what type of substrate sediment is EWM growing? Sediment can be characterized by partical size (sand, silt, clay) and organic content. • Is there a correlation between differences in substrate and EWM density or distribution?	• This can help prioritize treatment areas, and rank the vulnerability of areas outside the current EWM extent to future invasion.	• Samples can be collected with a benthic core or dredge sampler, collecting equal volumes at each site, taken to the same depth below the lake bottom.
Invertebrate Community (aquatic crustaceans, insects and worms)	• Are there significant changes in the aquatic invertebrate community pre and post-treament? • Are these changes positive for the lake ecosystem?	• Invertebrate communities serve as a useful indicator as they respond relatively quickly to changes in vegetation and environmental conditions. • Crayfish have been identified as having a potentially important connection with EWM, and would be particularly valuable indicators to monitor (although they are controlled by predators, not food availability (L. Gregory pers. comm.).	• Benthic invertebrate samples can be taken along with substrate samples. • Lentic invertebrate samples can be taken with drift nets. • Crayfish have been identified as having a potentially important connection with EWM, and would be particularly valuable indicators to monitor. One way to monitor crayfish populations is by setting traplines using baited minnow traps[14].

[14] https://www.muskokawatershed.org/wp-content/uploads/2011/12/Crayfish-KSomers1.pdf

Parameter Description	Key Questions	Application to EWM Management	Methodology Comments
Fish Habitat and Utilization Habitat quality Species utilization	• Has the fish habitat improved as a result of EWM management? • Is there any increase in native fish species relative abundance or habitat utilization post-treatment? • Conversely, is there a decrease in the relative abundance or habitat utilization of non-native fish? • Does the effect of EWM management (if any) on fish species abundance and habitat utilization depend on the underlying habitat characteristics?	• Relative abundance of fish species (native and non-native) and their utilization of habitats pre and post-treatment provide quantification of the expected benefits of EWM control for native fish and the lake ecosystem as a whole. • If particular habitat types exhibit better than average outcomes for native fish abundance and habitat utilization, these could be prioritized for treatment above other areas.	• Fish habitat characteristics, fish species relative abundance and habitat utilization could be assessed by snorkel and/or dive survey. • Beach seining may also be an appropriate sampling method at some monitoring sites. • A passive method of observing and quantifying fish habitat utilization is recording underwater video from a fixed station – such as setting up a GoPro attached to a stake that is anchored in the bottom. By recording for a fixed length of time, each video represents an equal effort sample with which relative species abundance can be compared between sample sites. • The above methods applied at monitoring sites would primarily provide information about juvenile fish – angling surveys may be an effective means of tracking adult fish populations in the lake (including participatory reporting by recreational anglers).
Public Perception Community surveys	• How much do community members perceive EWM to be a problem, before and after treatment? From one year to the next? • How effective do community members think the EWM management program is?	• Community surveys completed before and after control efforts would provide a way to gauge the perceived effectiveness of EWM management. • This is a simple way to evaluate the effect of EWM management on recreational and aesthetic values.	• This could be delivered in person at community EWM management workshops, as well as via community group email lists and in-person at public lake access points.

7.2.1 Monitoring

Restoration aims to re-establish pre-contact ecosystems that existed on a site. It also aims to take steps to reduce disturbances – examples in the case of Shawnigan Lake would be disturbances to riparian vegetation and to disturbances to the lake bottom. Sooke Lake (4 km south west of Shawnigan Lake) in the CRD watershed could be used as a reference ecosystem (a control) to obtain information (eg aquatic plant present, crayfish population) about what Shawnigan Lake may have been like 100 years ago [note that permission is required to access the CRD watershed area]. Reference ecosystems are used to define parameters for the ecosystem being restored where those features have been damaged, degraded or destroyed (Polster 2002). The goal of monitoring is to determine if ecosystems are responding as expected and whether the desired results are being achieved.

7.3 Experimental Design

As identified earlier in this management plan, there are numerous management measures that can be applied to control EWM. Which will be the most effective in Shawnigan Lake, and which will be cost-effective will depend on site-specific conditions. Rather than rushing to choose a management method to apply lake-wide, it would be worthwhile to conduct a multi-year experiment to evaluate a selection of techniques.

Treatment test plots should be established at permanent monitoring sites, particularly those around the fringe of dense patches of EWM where EWM cover is low to moderate. Another suitable test plot site would be an area where EWM has apparently recently invaded and has yet to establish a dense stand. The appropriate number and distribution of test plots would depend on the results of a baseline assessment, as well as the availability of resources.

7.4 Adaptive Management

This management plan is to be updated on an annual basis as new information becomes available and as conditions change. The purpose of a baseline assessment and annual monitoring is not just to track and evaluate the results of management efforts, but to provide feedback to improve management measures wherever possible.

7.5 Management Timeline

EWM has reportedly been present in Shawnigan Lake since the 1970s, becoming well-established and dispersing throughout the lake over the past five decades – this is a long-term problem with no quick solution. Effective control of EWM in Shawnigan Lake will require ongoing management on an annual basis over the long-term.

We recommend that a baseline assessment be conducted during the summer of 2018, followed by the development and implementation of an experimental design from 2018 to 2023. Results of the treatment experiments should be monitored for at least three to five years to evaluate the effectiveness of management measures. Once the most effective methods have been determined, a lake-wide EWM control strategy can be developed and implemented.

Depending on the planned intervention, a "Notification of Instream Work" will be required under Section 11 of the provinicial Water Sustainability Act. The involvement of a Qualified Environmental Professional (QEP) would also be required.

7.6 Budget and Funding

Numerous case studies confirm that the control of EWM can be very expensive. Moreover, the results of control efforts have been highly variable. As such, this is the type of problem that a significant amount of time and money could be spent with less than satisfactory results. Hence, we recommend approaching the problem with a thorough baseline study and experimental design to inform the prioritization of resource allocation.

Implementing management measures and monitoring on an annual basis over the long-term will require a reliable source of funding. While a significant portion of the baseline assessment and monitoring may be completed by volunteers, there may be costs involved for professional guidance, equipment, analysis of samples, data analysis and mapping, divers, benthic barriers, size of treatment area, number and duration of treatment (one, two or three years, or more) etc. Of course, implementing the EWM control measures lake-wide will represent the greatest cost.

It will be important for the community organizations spearheading the EWM control effort to partner with local, provincial and federal levels of government, and to identify potential funding sources. Funding for ongoing management efforts will likely be more attainable upon completing a baseline assessment and experimental design, as it will be apparent to potential funders that the management plan is built on a solid scientific foundation and that the results will be quantifiable.

7.7 Public Outreach, Education and Citizen Science

Public outreach and education is an essential component of invasive plant management. Community members should be directly involved in the development of this management plan, its goals and objectives, implementation and monitoring. If members of the public are aware of EWM and the control effort, the control of infestations will be more effective.

Community Meetings / Workshops should be organized to review this management plan and to collaboratively refine aspects of the plan, such as:

- Methodology for baseline assessment and monitoring;
- Timelines for the baseline study, monitoring and the implementation of management measures;
- Integration of community members (citizen scientists) into the monitoring plan;
- Identifying priority areas for the application of interim management measures; and
- Identifying potential funding sources and organizing grant proposal writing.

7.8 Acknowledgements

The majority of the data in this report was obtained from journal articles or seminar proceedings. Useful information was also obtained from concerned citizens (Kelly Musselwhite, Martinez de Saavedra Alvarez, Blaine Castle, and George Kohorst) regarding the locations of EWM and management recommendations. Thanks also to both in-house and external reviewers (L. Gregory, B.Hook, and A.Acton). This report was made possible by Richard (Dick) Nesbitt and Shawnigan Lake School.

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8 Author Credentials

Harry Williams, M.Sc., R.P.Bio., P.Ag, Certified Arborist
Qualified Professional Terrestrial Ecosystem Ecologist

Harry Williams has 25 years of experience as a vegetation ecologist in western Canada. He is a Professional Biologist, Professional Agrologist, Certified Arborist, Certified Environmental Monitor, and a Qualified Environmental Professional (QEP). He has a strong background in forest and vegetation ecology, ecosystem mapping (TEM, SEI, and PEM), rare plant surveys, invasive plant management, arboriculture, danger tree assessments, wetland classification and inventories, agriculture, land use planning, GIS, soils and surficial geology, riparian ecosystems, and wildlife sciences.

His other strengths include ecological classification, tree identification and taxonomy, physical geography, ecological restoration, wildlife habitat assessments, environmental legislation, and horticulture. With a background in linguistics, he is fluent in French and has working level Spanish.

Ian Wright, B.Sc., P.Ag., R.B.Tech.
Restoration Ecologist and GIS Analyst

Ian is a professional agrologist, biology technologist and GIS analyst with 5 years of experience in environmental consulting in BC. He has demonstrated expertise in the planning, design, implementation and monitoring of ecological restoration projects involving riparian areas, wetlands and aquatic habitats in both marine and freshwater environments. His interest in geography led him to pursue advanced training in GIS, which has provided him with skills in cartographic map production, geodatabase creation and management, and spatial analysis and modeling. These proficiencies have been valuable for the creation of map products for numerous projects, as well as watershed-scale habitat analyses involving the integration of provincial and private forestry datasets and the creation of new datasets based on high-resolution imagery and local ecological knowledge.

Environmental planning and monitoring of sensitive construction works is another of Ian's areas of expertise, including infrastructure projects, residential and commercial developments, and various works in or near aquatic environments. In addition, Ian has extensive experience in field assessments, data analyses and the development of mitigation measures as part of environmental impact assessments. He has collected and analyzed data pertaining to fish and wildlife values, plant communities, topography, water quality, hydrology, and is skilled in the use of differential GPS to collect high-accuracy spatial data.

In forestry and land development settings, Ian has proven experience in riparian assessments, as well as stream and wetland classification. His diverse project experience has enabled Ian to provide environmental services to a variety of clients including First Nations, private forestry companies, land developers, general contractors, crown corporations, and government agencies at municipal, provincial and federal levels.

Thomas R Elliot, PhD, P.Geo., P.Ag.
Hydrogeologist, Geoscientest and Agrologist

Thomas first practiced environmental consulting through hydrogeomorphologic assessment and watershed restoration of agricultural lands in the Sonora Desert. Using a blend of USGS approved and traditional knowledge methods, Thomas contributed to restoration of the Chochise Rio de Aqua Prieta – a significant regional watercourse. Since this start in 2002, he has upgraded his capacity through practice and academic pursuit of environmental engineering, geoscience, hydrology and agrology. These skills were reinforced by practical application in natural resource industries and federal government experience which contributed to state-level regulatory frameworks. In 2007 Thomas started a focused investigation of fluid transport in porous earth material funded by the Canadian national government and industrial partners. The deliverable of his investigation contributed to policy guidance on nutrient management and aquifer vulnerability assessments in Ontario. Thomas subsequently pursued a multidisciplinary approach to subsurface hydrology and reservoir management when overseeing applied structured decision making programs in Carbon Mitigation for Global Environmental Change under the auspices of Canadian and US government agencies as well as Canadian, US and International corporate entities.

Throughout his 14 years of practice, Thomas has demonstrated expertise in project management, geoscience and land use planning, agrology, remote sensing, hydrology, geomorphology, stratigraphy, process integration and optimization, numerical models, hydrogeology, natural resource development, environmental site assessment, as well and engagement and communication. Recent work includes terrain hazard management, soil slope failure and erosion mitigation, landscape and site hydrology, agricultural land assessment, development and application of land use optimization models for private and First Nation interests, as well as development permitting for private and commercial interests.

Thomas has been with Madrone since moving to British Columbia in 2014 and looks forward to delivering a high level of service through a multidisciplinary team approach to our Client Solutions.

Trystan Willmott, B.Sc., A.Sc.T.
Aquatic/Terrestrial Biologist

Since early 2005, Trystan has been involved with numerous fisheries and wildlife assessments, technical report writing, data collection and database building, as well as conducting GIS analysis of species and habitats. He has extensive experience in the completion of riparian assessments and developing environmental management plans for construction activities close to sensitive habitats (e.g. instream works). He is also experienced in completing fish sampling assessments to allow proper classification and management of streams for forestry.

Trystan is an Applied Science Technologist under the governing body of the Applied Science Technologists and Technicians (BC).

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APPENDIX I

Water Temperature and Dissolved Oxygen Tolerances for Native and Introduced non-Native Fish that Occur in Shawnigan Lake

Information in this Appendix discusses the tolerances of the various fish species that are present in Shawnigan Lake to water temperature and the amount of dissolved oxygen in the water, as these tolerances, along with their habitat preferences, affect how fish in the lake interact with EWM.

Unlike kokanee, coho salmon, rainbow trout and coastal cutthroat trout, the non-native introduced fish species that occur in Shawnigan Lake are more adaptable to warm water conditions. The yellow perch has an optimal summer temperature range between 21°C to 24°C (Scott and Crossman 1973; cited in Brown *et al.* 2009). The optimal water temperature range of Pumpkinseed fish is 24°C to 32°C (Holtan 1998; cited in Jordan *et al.* 2009). For smallmouth bass, the preferred summer rearing water temperature is between 21°C and 27°C.

In contrast to the non-native introduced fish, optimal rearing temperatures for native salmonids are much lower: 9°C to 16°C (coho salmon); 10°C to 15°C (sockeye/kokanee); 7°C to 16°C (coastal cutthroat trout); and 16°C to 18°C (rainbow trout) (MoE 2001). Water temperatures in excess of 23°C for even short periods of time (*i.e.* hours) result in movements of native salmonids into cold water refugia (Sauter *et al.* 2001).

In addition to being adapted to a wider range of water temperatures (*i.e.* having higher upper water temperature limits in comparison to native salmonids), non-native fish in Shawnigan Lake also have a higher tolerance for relatively low dissolved oxygen levels. Yellow perch can tolerate oxygen levels as low as 0.2-1.5 mg/l at low winter water temperatures (when fish metabolism is low), whereas a level of 3.1 mg/l is considered lethal at a high summer water temperature of 26°C (when metabolism is higher) (Moore 1942; Magnuson and Karlen 1970; cited in Brown *et al.* 2009). Pumpkinseed fish are known to tolerate dissolved oxygen levels lower than the tolerance levels of their relative, the bluegill (*Lepomis macrochirus*), which can tolerate levels less than 1.0 mg/l for short periods of time, with preferred levels above 3 mg/l (Stuber *et al.* 1982). Compared to yellow perch and pumpkinseed fish, smallmouth bass have a lower tolerance for low dissolved oxygen levels, with the optimum being above 6 mg/l for rearing, greater than 6.5 mg/l for embryo development and greater than 6.5 mg/l for spawning (Davis 1975; cited in Brown *et al.* 2009).

Native salmonids generally require much higher dissolved oxygen levels for all life-cycle stages. At the embryonic and alevin life-phases, a dissolved oxygen level less than 7 mg/l in the water column causes severe production impairment, less than 8 mg/l leads to moderate production impairment and less than 6 mg/l causes mortality. For life stages other than the embryonic or alevin phases, dissolved oxygen levels less than 5 mg/l can cause moderate production impairment, with levels less than 4 mg/l causing severe production impairment and less than 3 mg/l causing mortality (USEPA 1986).

APPENDIX II

Identification Key for the Genus *Myriophyllum* in the Pacific Northwest

The following excerpt is from Ceska and Ceska (2010), accessed via E-Flora BC:

GENUS *MYRIOPHYLLUM* (HALORAGACEAE) IN THE PACIFIC NORTHWEST

From: Oldriska Ceska and Adolf Ceska aceska@telus.net

For the accompanying figures see: http://bomi.ou.edu/ben/428/myriophyllum_ben428.pdf

1. Leaves alternate or in whorls with additional alternate leaves scattered outside the whorls.
    2. Flowers in axils of submerged leaves, not forming terminal spikes; alternate leaves more common than those in whorls.................................. *M. farwellii*
    2. Flowers in terminal spikes in axils of bracts; leaves essentially in whorls with some alternate leaves scattered on the stem.
        3. Fruits (mericarps) with tiny warts on the dorsal ridges.............................M. pinnatum
        3. Fruits (mericarps) with glabrous, rounded dorsal ridges.
            4. Stems whitish, lighter than the leaves; leaves dark green; bracts shallowly sharp-toothed; bracteoles at the base of flowers 1-1.3 mm long; petals 1.5-3 mm long; mericarps prominently beaked from a persistent stigma .... *M.heterophyllum*
            4. Bracts comb-like; bracteoles at the base of flowers 0.6-0.7 mm long; petals 1-2 mm long; mericarps without permanent beaks ....M. hippuroides
1. Leaves in regular whorls or opposite, but without any additional alternate leaves scattered outside the whorls.

5. Plants dioecious usually forming single populations of the same sex.
    6. Plants robust; stems 2-5 mm in diameter; leaves usually in whorls of 5 to 8
    6. Plants delicate; stems 1-2 mm in diameter; leaves in whorls of 3 or 4, often also opposite .... *M. ussuriense*
5. Plants monoecious, male and female flowers in the same inflorescence.
    7. Floral bracts pinnate......... *M. verticillatum*
    7. Floral bracts entire or dentate.
        8. Young shoots with one or several parts of entire leaves at the base; plants with strong whitish rhizomes; flower bracts triangular, over 4 mm long, toothed; bracteoles 1.0-1.5 mm long...................... M. quitense
        8. Young shoots lacking entire leaves at the base; plants usually without whitish rhizomes;flower bract lanceolate,less than 4 mm long, entire or shallowly notched, lacking a waxy bloom; bracteoles less than 1.0 mm long.
            9. Leaves with 14-24 pairs of segments;segments declined in sharper than 45° angle; segments parallel to each other throughout the whole leaf .... *M. spicatum*
            9. *Leaves with 4-14 pairs of segments; segments* declined from 45° angle to almost perpendicular to the axis of the leaf, angles varying throughout the leaf .... *M. sibiricum*

Species Descriptions

Myriophyllum aquaticum (Vell.) Verdc. - Parrot's-Feather Syn.: M. brasiliense Camb., M. proserpinacoides Gillies ex Hook. & Arn. Introduced in North America from South America. Dioecious, only female plants known in North America. Easily recognized by thick stems, firm leaves and overall bright green colour. Winter buds absent.

Myriophyllum farwellii Morong - Farwell's Water-Milfoil North American species distributed in eastern North America; in the Pacific Northwest known from Alaska & British Columbia. Easily overlooked since it grows relatively deep at the bottom of dystrophic lakes. Usually copiously fruiting at the base of the stem leaves. Winter buds absent.

Myriophyllum heterophyllum Michx. - Two-Leaf Water-Milfoil Introduced to Alberta, British Columbia and Washington from eastern North America. In BC it occurs in a park ponds in Vancouver. Easily recognizable by whitish stems and leaves in pseudowhorls. Winter buds absent.

Myriophyllum hippuroides Nutt. ex Torr. & Gray - Western Water-Milfoil Occurs from California to the Lower Fraser Valley in British Columbia; there it forms dense stands in sloughs of the Fraser River and its tributaries. Easily recognized by deep green colour, dense foliage with additional numerous leaves outside the whorls. Winter buds absent.

Myriophyllum pinnatum (Walt.) B.S.P. - Cut-Leaf Water-Milfoil Eastern North American species with disjunct occurrences in British Columbia, Washington and Oregon. Recognized by the dark-green stems and foliage. Winter buds not seen.

Myriophyllum quitense Kunth - Andean Water-Milfoil Syn.: *M. elatinoides* Gaud. South American species that extends to western USA and to British Columbia; also in eastern Canada. It occurs in wind-swept parts of large lakes or in flowing water of rivers. Dried herbarium specimens are dark grey. The lowermost leaves are reduced to bract-like structures and the system of strong whitish roots are the best identification characters of the sterile plants. Winter buds absent.

Myriophyllum sibiricum Komarov - Siberian Water-Milfoil Syn.: *M. exalbescens* Fern.; *M. spicatum* subsp. *exalbescens* (Fern.) Hultén Native to North America, northern Europe and eastern Asia, widespread in North America (except Texas and SE states). Stem whitish, leaves with smaller number of "untidy" segments. Winter buds frequent, cylindrical.

Myriophyllum spicatum L. - Eurasian Water-Milfoil introduced and invasive. North American invasive populations are considered tobe of a hybrid origin [*M. spicatum* x *M. sibiricum*] by Moody & Les (2002, 2007). Stem drying reddish. No winter buds.

Myriophyllum ussuriense (Regel) Maxim. - Ussurian Water-Milfoil Syn.: *M. isoetophyllum* Komarov Amphiberingian species, Far East of Asia and British Columbia, Washington and Oregon. Dioecious, population clonal, usually of one sex (female populations prevailing) some populations rarely with hermaphroditic individuals. Terrestrial or semiterrestrial at the margins of lakes and rivers with fluctuating water table, truly aquatic plants rare. Habit is unlike of any other our milfoil. Winter buds inconspicuous, filiform.

Myriophyllum verticillatum L. Whorled Water-Milfoil Circumpolar species. Occurs sporadically throughout Canada, Pacific Northwest, and NE parts of the USA. Stems and leaves green, leaves often with "myriophylloid glands" at the base of the lowermost segments. Winter buds frequent, clavate.