Review of Eurasian watermilfoil control at Cultus Lake and recommendations for future removals

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Executive Summary

Eurasian watermilfoil (*Myriophyllum spicatum*) is an exotic perennial plant that grows in dense clumps in the littoral zone of lakes. Eurasian watermilfoil can affect sockeye salmon directly by encroaching on spawning areas, or indirectly by affecting the abundance of sockeye predators. We review existing information on Eurasian watermilfoil distribution and removal activities at Cultus lake to help provide an informed assessment and evaluate the likelihood that future control can increase juvenile sockeye survival and improve sockeye spawning conditions.

Juvenile northern pikeminnow (*Ptychocheilus oregonensis*) are abundant near Eurasian watermilfoil mats and the introduction of Eurasian watermilfoil at Cultus Lake appears to have provided a biologically important amount of ‘new’ habitat for juvenile pikeminnow and other fishes. Adult pikeminnow feed on juvenile sockeye when sockeye are abundant. It has been hypothesized that milfoil provides refuge for juveniles from cannibalism by conspecifics, but there is little direct evidence to support or refute this mechanism. Large-scale Eurasian watermilfoil control to reduce habitat for juvenile pikeminnow would not affect the adult pikeminnow population (and thus sockeye predation) until the affected juvenile cohorts grow to a size where they become piscivorous (at least three years). Similarly, Eurasian watermilfoil control at spawning areas is unlikely to benefit sockeye spawning over the next few years (when returns are expected to be low) because there are likely enough suitable spawning areas. However, benefits are may be realized over the long term if a sustained control program is instituted.

Mapping of sockeye spawning areas and surveys of EWM distribution are needed before a Eurasian watermilfoil control plan can be developed. These surveys should be a priority for the summer and fall of 2004, and, if deemed necessary, Eurasian watermilfoil control could begin as early as the winter of 2004-2005.

Introduction

Cultus Lake is a small (6.3 km^2) lake in the lower Fraser Valley of British Columbia that supports a run of sockeye salmon (*Oncorhynchus nerka*) that are genetically distinct from other Fraser River stocks (summarized in Schubert et al. 2002). Sockeye salmon escapements to Cultus Lake have declined precipitously in recent years due to a number of factors, and the stock is at a risk of extinction (Schubert et al. 2002). Harvest restrictions and other measures designed to conserve and rebuild this run will have significant socio-economic costs.

The impacts of the introduction of Eurasian watermilfoil (*Myriophyllum spicatum*) on sockeye survival and spawning habitat have been a concern since the early 1980s (Schubert et al. 2002). Eurasian watermilfoil (EWM) can encroach on spawning areas and can potentially affect predation on juvenile sockeye by providing habitat for sockeye predators. To help provide an informed assessment and evaluate the likelihood that future EWM control can increase juvenile sockeye survival and improve sockeye spawning conditions in Cultus Lake, we review existing information on EWM distribution and removal activities at Cultus lake. We also summarize findings of past studies, review and evaluate available EWM control methods, and provide recommendations on future EWM control activities.

1. Ecology of Eurasian watermilfoil

EWM is an exotic macrophyte that grows in dense clumps in the littoral zone of lakes. The rapid growth and propagation of this perennial aquatic plant allow it to rapidly colonize new areas and out-compete native plants. A mass of root fibres up to 0.5 m in diameter firmly anchors up to 100 stems to the lake bottom. The stems of plants rooted in less than roughly 5 m of water reach the water surface and branch to form of a dense tangle of growth. The growing season lasts from May to November (Newroth 1993). Stems grow rapidly during the summer and break away from the root late in the season, leaving the root mass to overwinter.

EWM propagates mainly by fragmentation (asexual reproduction). Waves, currents, and boat wake help to dislodge and transport fragments. EWM can grow on fine silt, sand, gravel, and spaces between larger rocks. Fragments reportedly do not ‘take’ at water temperatures <10°C. EWM can colonize depths from 1 to 10m deep and is most common from 1 to 3 m deep (Aiken et al. 1979). Wave action prevents growth in water <1 m deep and light penetration limits growth in deeper water. At Cultus Lake, EWM is most common from 1 to 4 m deep (Gregory 1991; Ken Morton, unpublished data).

2. History of milfoil in Cultus Lake

Note: There is no comprehensive review of EWM at Cultus Lake and most information comes from annual reports, minutes from meetings, and personal communications.

EWM was first observed at Cultus Lake in 1977. Annual milfoil surveys during the fall from 1977 to 1991 showed that EWM is widespread in the lake. Infestation[1] increased steadily from 12.7 ha in 1977 to 21.5 ha in 1991 (Table 1), or from 17 to 29% of the 74 ha littoral area (Truelson 1992). This increase occurred in spite of EWM control efforts (discussed below). No surveys have been completed since the early 1990s. Anecdotal reports suggest that the current EWM abundance is higher than during the 1990s, though opinions vary.

EWM control began in 1978 (Newroth 1993) and has continued until 2003 (Table 1). At the time of writing, no program is scheduled for 2004. Rototilling (see section 4.1) was the primary control method and occurred from May or June until early in August (Table 1). Bottom-barriers (see section 4.2) were also employed in areas that could not be accessed by the rototiller due to rocky substrates or limited access due to wharves. In most years, divers handpicked EWM that had rooted through the barriers and a pressure washer was used to clear accumulated sediment. Control effort was greatest during the early and mid-1990s (Table 1) and was concentrated on 8 ha of high-use recreational areas scattered around the lake (see Truelson 1992; Dyck 1994). In recent years, removals have occurred at the dock area near Main beach, the Sunnyside campground, the Provincial Park swimming areas, and Lindell Beach (Grant Sanborn, CLBP, and Jim Wiebe, BC Parks, personal communication).

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[1] Measured as EWM presence. EWM density (% coverage) was also surveyed.

Table 1. Summary of Eurasian watermilfoil control at Cultus Lake. Data are from annual reports and personal communications. Blank cells indicate that data were not available.

Year	Control (Y/N)	Survey[a] (Y/N)	Area infested (ha)	Rototill: Operating hours	Rototill: Dates	Rototill: Area tilled (ha)	Barrier cleaning (ha)
1977	N	Y	12.7				
1978	Y	Y	14.7				
1979	Y	Y	16.0				
1980	Y	Y	16.6				
1981	Y	Y	17.4				
1982	Y	Y	18.0				
1983	Y	Y	18.3				
1984	Y	Y	18.8				
1985	Y	Y	19.3				
1986	Y	Y	19.8				
1987	Y	Y	20.2				
1988	Y	Y	21.2			6.5	0.35
1989	Y	Y	21.0				
1990	Y	Y	21.5				
1991	Y	Y	21.5	226	Jun 3-Aug 12	8	0.35
1992	Y	Y			May 6-Jul 6		
1993	Y	?					
1994	Y	?		234	Jun 2-Aug 8	8	0.35
1995	Y	N		200			
1996	Y	N		219			
1997	Y	N		100-125			
1998	Y	N		100-125			
1999	Y	N		100-125			
2000	Y	N					
2001	Y	N					
2002	Y	N					
2003	Y	N					

[a] Additional surveys of sockeye spawning areas occurred at Lindell Beach in 1982-84 and 1989.

The Fraser Valley Regional District (FVRD) and the Cultus Lake Parks Board (CLPB) administered the EWM control program. BC Ministry of Environment, BC Parks, Canadian Forces Base Chilliwack, Fisheries & Oceans Canada, and possibly other groups (e.g., local resident associations) contributed to the program (Table 2). In general, the Water Quality Branch of the BC Ministry of Environment provided most (50-75%) of the funds up until the mid 1990s, while the FVRD and CLPB were the major contributors in last few years. Annual costs for milfoil removal ranged from $15,000 in recent years (reported in Schubert et al. 2002) to $22,000 in 1991 (Truelson 1992). The major costs of the removal program were for the rototiller (see below) and operator. Currently, rototiller ‘rental’ (calculated based on a cost-recovery basis) is roughly $300 / day and it uses $50 / day in fuel (Greg Armour, Okanagan-Basin Water Board, personal communication). Operator rates vary. In 1991, the rototiller covered 0.18 ha / 7.5 hour day.

Table 2. Agency contributions to the Eurasian watermilfoil control program at Cultus Lake. Information obtained from Truelson (1992), and personal communications with Jim Wiebe (BC Parks) and Grant Sanborn (CLPB).

Agency	Contribution
Fraser Valley Regional District	$ Contributions and ran the program
Cultus Lake Parks Board	$ Contributions and administered the program
BC Ministry of Environment	Provided most (50-75%) of the funding up to the mid 1990s
BC Parks	$7-10k annually during early 1990s, decreased to $2k annually in 2002 & 2003
Can. Forces Base Chilliwack	In-kind contribution in some years: dive team, water pump, rototiller transport from Vernon
Fisheries and Oceans Canada	Small ($1k) contribution in some years for benefits to sockeye spawning areas

One rototiller is shared three-ways between the Okanagan Regional Districts[2], the Columbia Shuswap Regional District, and the Fraser Valley Regional District. Cultus was the lowest priority user of the rototiller, which was only available for use at Cultus from the end of May to mid-August (Fig. 1). In the future, the rototiller may be available during the winter (Greg Armour, Okanagan-Basin Water Board, personal communication).

3. Impacts of EWM

3.1 Biological impacts

EWM can affect sockeye directly by encroaching on spawning areas, or indirectly by affecting the abundance of predators. EWM also affects water quality and displaces vegetation. We summarize these impacts in the following sub-sections.

[2] Administered by the Okanagan-Basin Water Board, which represents the three regional districts in the Okanagan.

3.1.1. Habitat for juvenile northern pikeminnow

EWM can provide important habitat for juvenile northern pikeminnow (*Ptychocheilus oregonensis)*. Adult pikeminnow can be an important predator of juvenile sockeye at Cultus Lake, at least when sockeye are abundant (reviewed in Mossop and Bradford 2004). Thus, EWM may affect sockeye survival indirectly by increasing the recruitment of adult pikeminnow and, as a consequence, increase predation on sockeye. In this section, we briefly review the habitat preferences of juvenile pikeminnow, their use of EWM as a refuge from predators, and estimate the amount of habitat provided by EWM.

Age 0 pikeminnow remain near shore during the summer and move offshore during the fall (Scott and Crossman 1973). During July and August, age 0 pikeminnow in Cultus Lake were commonly observed in very shallow water (<0.5 m), or rearing in or near EWM in water 1.5 to 4 m deep (Gregory 1991). These habitats provide a refuge from predators, which might include larger pikeminnow (discussed below). Juvenile pikeminnow (35-200 mm, ages 1 to 4) were observed directly above or on the edges of EWM mats during July and August, while adult pikeminnow (≥200 mm) were observed on occasion near the bottom just offshore from the EWM mats (Gregory 1991). Trout and char also eat young squawfish on occasion (Foerster and Ricker 1938). EWM may also provide a preferred rearing area, possibly with more food. Abundance of age 0 fish was related to EWM density in other lakes (Keast 1984; Gregory and Powles 1985). Thus, it appears that the introduction of EWM to Cultus Lake has provided a 'new' habitat for juvenile pikeminnow.

To estimate the area of 'new' juvenile pikeminnow habitat that EWM could provide, we used bathymetric data (Jeremy Hume, DFO, unpublished data) to calculate the lake area that EWM could potentially colonize. We calculated the area between 1 and 6 m deep because EWM is common at these depths. While EWM at Cultus Lake is most common from 1 to 4 m deep (Gregory 1991; Ken Morton, unpublished data), EWM at Cultus Lake could potentially grow in water at least 10 m deep. Therefore, we used 6 m to obtain a conservative estimate. We calculated planar areas (slope of the lake bed not taken into account) to allow a comparison with earlier EWM mapping. We estimated that there are 27.2 ha between 1 and 6 m deep. For comparison, Truelson (1992) estimated that EWM covered 21 ha in 1991.

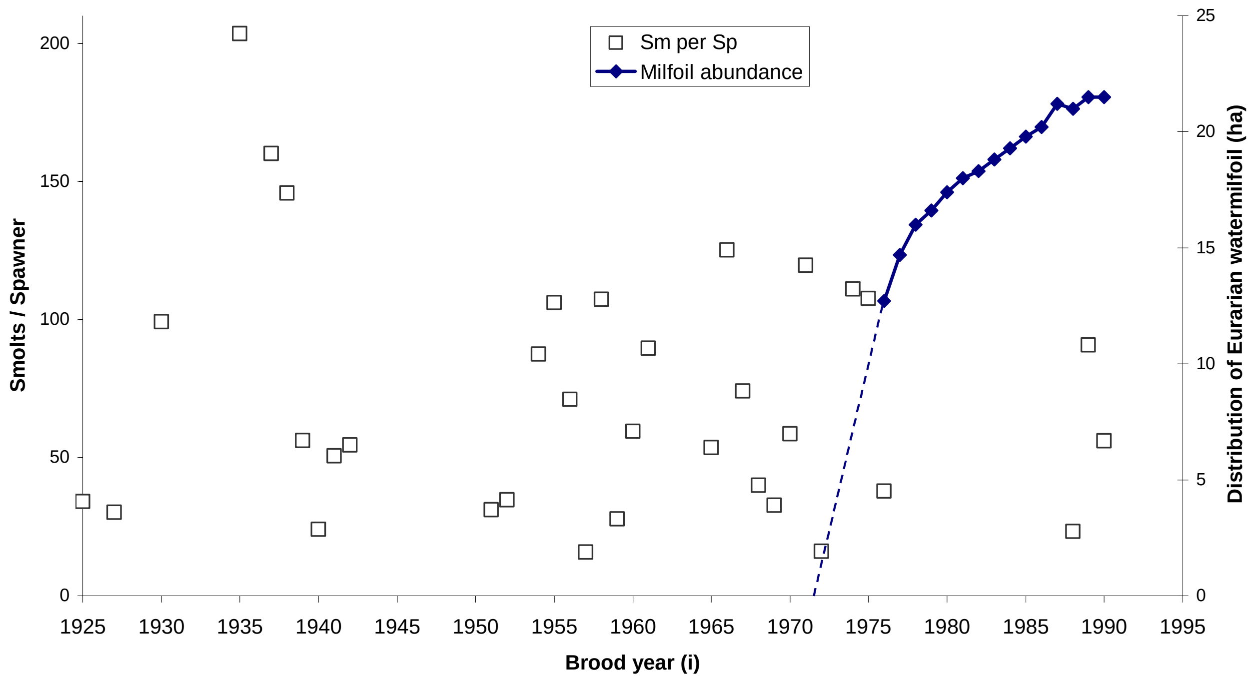
To allow a comparison with age 0 pikeminnow habitat specifically, we also calculated the lake area <0.5 m deep. Age 0 pikeminnow were present at similar abundances in water <0.5 m deep and in EWM habitats in deeper water (Bob Gregory, DFO, personal communication). They were generally not observed in deeper water (>1 m) that lacked EWM, including areas that had been rototilled the previous summer (Gregory 1991). We calculated 0.49 ha <0.5 m deep. Thus, if EWM were to colonize the entire lake area between 1 and 6 m deep, EWM could provide an additional 26.7 ha of age 0 pikeminnow habitat, or a 56-fold increase in habitat. This comparison assumes that native macrophytes provided little pikeminnow habitat prior to the introduction of EWM. While data on the distribution of native macrophytes is limited, their distribution was likely much less than that calculated for EWM. The large area of EWM colonization (either the calculated potential distribution or surveyed distribution in 1991) suggests that EWM has provided a biologically important amount of 'new' habitat for juvenile pikeminnow.

While pikeminnow cannibalism at Cultus Lake is often discussed (e.g., Foerster and Ricker 1953; Ward 1953; Gregory 1991; Schubert et al. 2002), pikeminnow have not been found in the digestive tracts of pikeminnow. Pikeminnow were not listed as prey items in stomachs of over 3000 pikeminnow examined during the 1930s (Ricker 1941). None of the 162 pikeminnow stomachs examined in late-June 1991 contained pikeminnow (Gregory 1991). The only evidence of cannibalism at Cultus Lake (or elsewhere) that we are aware of comes from an experiment that documented attacks by larger pikeminnow on juvenile (age 1-2) pikeminnow that were attached to a tether in shallow water (Gregory 1991). However, even if pikeminnow cannibalize their young only rarely (i.e., 1 or 2 per year), it could have a significant effect given the abundance of adult pikeminnow in the lake. Even if pikeminnow do not cannibalize their young, EWM appears to provide an important habitat for juveniles that likely benefits the recruitment of adults. Ward (1953) hypothesized that reduced cannibalism following pikeminnow removals during the 1930s contributed to the rapid rebound in the pikeminnow population. Cannibalism and the refuge provided by vegetative cover have been documented for other species. Reduced cannibalism on juvenile northern cod (*Gadus morhua*) near eelgrass beds has been documented (Bob Gregory, DFO, personal communication). Increased cannibalism following the removal of macrophytes has been documented for northern pike (*Esox lucius*) in an Ontario lake (Ken Mills, DFO, Winnipeg MB, personal communication with Mike Bradford).

The introduction of EWM in the late 1970s may have contributed to apparent changes in the relative abundance of fish species at Cultus Lake (summarized in Mossop and Bradford 2004). From the 1930s to 1991, the abundance of northern pikeminnow, largescale sucker

(*Catostomus macrocheilus*), and mountain whitefish (*Prosopium williamsoni*) appears to have increased relative to the abundance of trout and char. Population estimates for adult (≥200 mm fork length) pikeminnow suggest that abundance increased from 20,000 in 1969 (Steigenberger 1972) to 38,100 in 1991 (Hall 1992).

Fig. 2. Cultus Lake sockeye smolts per spawner by brood year and the corresponding distribution of Eurasian watermilfoil during the year that fry were rearing in the lake. Data sources are described in Mossop and Bradford (2004). Note that density dependent effects on sockeye survival are not illustrated.



Declines in the escapement of Cultus sockeye salmon started in the late 1960s (Schubert et al. 2002), and it is not clear whether declines can be attributed in part to the proliferation of EWM in the late 1970s. Visual inspection of Fig. 2 suggests that there is no evidence that sockeye survival (measured as smolts per spawner) has decreased since the introduction of EWM, though there are few years of data[3] since EWM was introduced. Nevertheless, the proposed mechanism (EWM benefits pikeminnow which feed on sockeye) and supporting data

[3] Smolt per spawner data since the mid-1990s was not used due to data issues with pre-spawn mortality.

described above suggest that an inverse relation is possible. It seems likely that EWM can increase recruitment of adult of pikeminnow and, therefore, controlling EWM could affect the population of adult pikeminnow over the long-term. Juvenile pikeminnow were not abundant in areas that had been rototilled the previous summer (Gregory 1991). The adult pikeminnow population in 1990 was large (see Mossop and Bradford 2004) despite ongoing EWM control.

Unfortunately, controlling EWM is unlikely to greatly increase sockeye survival over the next few years for two reasons. First, EWM control would not affect the adult pikeminnow population (and thus sockeye predation) until the affected juvenile cohorts grow to a size where they become piscivorous (at least three years). Second, studies suggest that pikeminnow eat few sockeye when sockeye abundance is low (see Mossop and Bradford 2004), as is expected in the near future. In summary, controlling the overall abundance of EWM in the lake may provide some benefit to sockeye survival over the long term, but is unlikely to increase juvenile survival in the short term.

3.1.2. Encroachment on sockeye spawning habitat

The encroachment of EWM on sockeye spawning beaches at Cultus Lake has been a concern since the early 1980s. Dive surveys during this period showed that dense patches of EWM displaced spawning sockeye from areas at Lindell Beach, and that spawners returned to these areas after EWM was removed (Ken Morton, unpublished data). Cultus sockeye spawn exclusively in the lake, generally within 60 m from shore and in water 0.5 to 6 m deep (Schubert et al. 2002); the same depths that are commonly colonized by EWM. Encroachment on beach spawning areas has also been a concern at Shuswap Lake, BC (Newroth 1993). EWM was removed from spawning gravel to help kokanee in Okanagan Lake, BC (The Kokanee Salmon Heritage website[4]).

EWM encroachment could potentially affect the quantity or the quality of available spawning habitat for sockeye. EWM could limit the available spawning area or could potentially displace sockeye from high quality to less suitable spawning habitats. The former would only be of concern when spawner abundance is high, while the latter would be of concern at both high and low abundance. Given the expected low abundance of sockeye in the near future, there are

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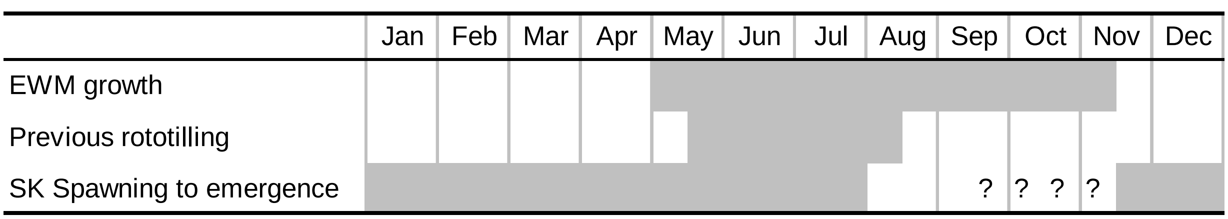
[4] http://royal.okanagan.bc.ca/kokanee/reproj.htm As viewed on Mar 30 2004

likely enough suitable spawning areas (Schubert et al. 2002) and the effect of EWM on spawning habitat quality would be of greatest concern. However, mapping of sockeye spawning areas and EWM distribution (see section 5) is needed to document the extent of EWM encroachment on spawning areas. While EWM has clearly displaced spawning sockeye in the past, it is not clear whether EWM forced sockeye to spawn in less suitable areas.

If EWM surveys in spawning areas show that encroachment is a concern, EWM control in spawning areas should follow certain precautions to protect sockeye redds. Sockeye spawning areas should not be disturbed during spawning, incubation, and emergence—from the start of sockeye spawning in late Nov until the end of July when fry have emerged and moved out of the littoral zone (Fig. 1). Sockeye may also be present near spawning areas prior to the start of spawning. A July 15 to Sept 15 window for work near spawning areas may have been suggested on one document (hand-written comments, Aug 17 2000 Milfoil Management Plan committed meeting minutes).

Fig. 1. Timing of Eurasian watermilfoil growth, previous rototilling, and sockeye spawning, incubation and emergence. The period when sockeye may be near spawning areas prior to spawning is indicated with a '?'.



Redd digging by chum salmon (*O. keta*) in the Fraser River can keep spawning areas clear of rooted plants (M. Foy, DFO, personal communication). Thus, spawning sockeye and chum salmon[5] at Cultus Lake may naturally keep spawning areas clear of EWM. However, the low sockeye returns in recent years and the expected low returns in the near future are likely too low to keep spawning areas clear.

Some spawning areas have groundwater that percolates at 8ºC year round (Schubert et al. 2002) and EWM fragments will not colonize when water temperatures are <10ºC. It would be

[5] During the early 1980s, chum carcasses were noted during late-fall milfoil surveys at Lindell Beach.

interesting to determine whether EWM can in-fact colonize these areas. EWM grew well in areas with groundwater influences in Kalamalka Lake, BC (Newroth 1993)

3.1.3. Water quality

While EWM can affect water quality, we do not suspect that these effects would be important for sockeye. In a Wisconsin Lake (Unmuth et al. 2000), water temperature and dissolved oxygen concentrations during the summer differed between dense EWM patches unvegetated areas. However, Cultus sockeye rear offshore during this time. EWM can alter the movement of sediment into deeper water and contribute to the deposit of sediments along the shoreline (letter dated Jun 5 1993 from M.D. Maxnuk, BC Environment, Water Quality Branch), which could affect spawning areas. EWM can take also up nutrients from the water or the sediment and release these nutrients when the stems decompose.

3.1.4. Native vegetation

EWM can out-compete and displace native vegetation in the lake. Again, we do not suspect that these effects would be important for sockeye because juvenile sockeye do not rear in the littoral zone. The native *M. exalbescens* (common water milfoil, also known as *M. sibiricum*) is noted in Truelson (1992) as being nearly completely displaced by EWM. Vegetation surveys at Lindell Beach in October 1989 documented the presence of Canada water weed (*Elodea Canadensis*) and several species of pondweed: *Potamogeton perfoliatus*, *P. gramineus*, and *P.'filiform'*. Curly leaf (or crisped) pondweed (*P. crispus*) was also growing in dense clumps at Lindell Beach in the fall of 1989.

3.2. Impacts on recreation

EWM affects boating, swimming, and fishing at this important recreation destination that receives approximately 1.5 million visitors annually. While recreation and aesthetic impacts are not the focus of this report, they are listed here because these impacts motivated previous control programs at the lake. Control to mitigate for impacts to recreation may occur in the future and, therefore, control work aimed specifically to benefit sockeye would have to be coordinated with such programs.

4. Control options

In lakes such as Cultus where EWM is well established, control generally focuses on maintaining the abundance of EWM at an acceptable level over the long-term. Eradication of EWM has only been documented in small ponds (Newroth 1993). Here, we review techniques to control EWM and Appendix 1 summarizes the advantages and disadvantages of these techniques for use at Cultus Lake. Much of the information comes from the Washington State Department of Ecology website (Appendix 2).

4.1 Mechanical control

Rototilling (de-rooting): A rototiller is a large, powered vessel that carries a modified rototiller whose rotating blades break up the plant's roots to a depth of 20 to 25 cm (Fig. 3). Dislodged roots and stems disperse in the lake and often wash up on shore. Rototilling is an efficient way to treat large, open areas and re-colonization takes 1 to 2 years. Rototilling is limited by rocky bottoms (large rocks also damage the blades), wharves, submerged logs, and underwater structures such as pipes. Rototilling can also re-suspend toxic material in the sediment. Rototilling is most effective during cool winter and spring months because only the EWM roots are present and dislodged fragments will not re-sprout given the cold water temperatures. Rototilling during the growing season (May-Nov; Fig. 1) can help to disperse EWM fragments. While EWM is already widespread at Cultus Lake, rototilling during the growing season may facilitate re-colonization of cleared areas. Rototilling is more commonly used in British Columbia lakes than in the western United States.

Rototilling during the summer has been the primary method of EWM control at Cultus. During some years, rototilling removed EWM from sockeye spawning areas at Lindell Beach (Newroth 1993). Rototilling dates (Table 1) overlap with the period of fry emergence (Fig. 1) and it is not clear whether rototilling near spawning areas was timed to occur after fry emergence.

Fig. 3. Example of a rototiller.

Harvesting: Harvesting is best described as 'underwater lawn mowing'. A large machine cuts and removes the top 1.5 m of the EWM stems (Fig. 4). Harvesting would have no potential benefit to sockeye spawning and would have little effect on pikeminnow rearing because juvenile pikeminnow rear near the top and edges of the plant.

Fig. 4. Example of a harvester (from the Washington State Department of Ecology website)

4.2 Bottom barriers (shading)

Bottom barriers are similar to landscape cloth or fabric weed barriers used in the garden. When secured on the bottom of the lake, they prevent plant growth by shading light. They are effective for treating small areas that cannot be treated with a rototiller. Barriers are generally left in place for years but are also effective when moved every few weeks during the growing season (May-Nov; Fig. 1). Barriers need annual cleaning to remove accumulated sediment and plants that have grown through the fabric. Barriers would prevent sockeye spawning.

Bottom barriers have been used effectively at Cultus Lake (e.g., Dyck 1994). Barriers installed in the early-80s had not deteriorated in 1994 (Dyck 1994). Texel Tac 150 (manufacturers website in Appendix 2) was an effective and durable material (Truelson 1988). Bottom barriers may be a useful spot treatment in spawning areas that cannot be accessed by the rototiller. However, barriers could only be installed in spawning areas during part of the EWM growing season, from after fry have emerged in late July until the end of the EWM growing season in early Nov (Fig. 1). Sockeye begin to spawn in late November (Schubert et al. 2002).

4.3 Chemical control

Several aquatic herbicides are effective at controlling EWM (Appendix 1). However, they may not be feasible at Cultus Lake because the chemicals can present a real or perceived risk to water quality. Chemical treatments are used more frequently in the western United States than in British Columbia.

4.4 Biological control

Biological control of EWM by herbivores that are native to western North America, such as the milfoil weevil (*Euhrychiopsis lecontei*) and the midge *Cricotopus myriophylli*, has been documented. However, the science and management applications for these controls are not fully developed (Creed 1998; Creed 2000; Sheldon and Creed 2003). Developments in this area should be followed for potential application in the future.

4.5 Summary of control options

Rototilling appears to be the only large-scale control method that is suitable for Cultus. Although the overall abundance of EWM increased during previous control efforts, rototilling was an effective at controlling EWM in targeted areas. Dispersal of EWM fragment from rototilling is not a major concern because EWM is widespread at Cultus. If the equipment is available, rototilling during cooler months in the fall and winter (but not on spawning areas after the end of October) is preferable because less plant biomass is present and dispersed fragments will not re-sprout. Bottom barriers are also an effective spot treatment and could be used in spawning areas at certain times of the year. Hand picking is also an option for spawning areas.

5. Components of EWM control programs

Components of an EWM control program include (1) program objectives, (2) an assessment of EWM distribution, (3) a control plan tailored to the specific conditions in the lake and available resources, and (4) follow-up monitoring to assess the success of removals. We review each of these components below.

Objectives

EWM control to benefit sockeye would include two objectives:

1) Control the overall abundance of EWM in the lake to reduce available habitat for juvenile pikeminnow and, consequently, to control the adult pikeminnow population over the long term.
2) Keep sockeye spawning areas clear EWM to ensure that sufficient spawning areas are available.

Assessment of EWM distribution and monitoring

EWM distribution and density should be surveyed at least annually to assess the success of EWM removal and help direct future control. Surveys during the fall can measure the success of removals that occurred that year and provide an estimate of the EWM abundance that will be present the following year. To be comparable with existing surveys, EWM surveys should follow the methods used in previous surveys, which apparently were consistent over time. Newroth (1993) generally describes EWM survey techniques. Surveys in British Columbia lakes during the 1990s generally employed SCUBA surveys where the diver was towed. The exact methods used at Cultus are not described in annual reports and should be confirmed with the personnel that conducted the surveys (Appendix 3). EWM surveys could also be coordinated with sockeye spawning surveys.

Control plan

A control plan cannot be developed until EWM distribution is surveyed and the availability of equipment is determined. Nevertheless, given that EWM abundance is suspected to be high, a control plan would likely include: (1) rototilling to control overall EWM abundance, preferably during the winter if equipment is available, and (2) a combination of rototilling, bottom barriers, and possibly hand picking to control EWM at spawning areas. Groundwater surveys could be used to identify potential spawning areas, since sockeye generally spawn in areas with groundwater inflow. Thus, areas with strong groundwater inflows should be a priority for EWM control.

6. Research opportunities

The impacts of EWM on salmonids are poorly documented in the primary literature, and research opportunities are possible. The role of EWM as pikeminnow habitat and the effects of EWM removal on the pikeminnow population could be examined. Developing age-structured population models for pikeminnow would be useful for these investigations.

7. Recommendations

Mapping of spawning areas and surveys of EWM distribution (section 5) are needed before a EWM control plan can be developed. Once EWM distribution and encroachment on spawning areas has been determined, a control plan can be developed based on the guidelines presented in sections 3 to 5. EWM control during the summer of 2004 would not likely benefit sockeye returning over the next few returns years (when returns are expected to be low) because we suspect that sufficient spawning areas are present, changes to the adult pikeminnow population from EWM control would not occur for several years, and pikeminnow eat few sockeye when sockeye are not abundant. Thus, mapping and surveys should be the priority for the summer and fall of 2004, and, if deemed necessary, milfoil control could begin as early as the winter of 2004-2005. In anticipation of EWM control work, the availability of equipment should be determined and plans should be coordinated with local agencies and stakeholders (see Appendix 3).

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Appendix 1. Summary of potential Eurasian watermilfoil control methods and their advantages and disadvantages for use at Cultus Lake. Data are primarily from the Washington State Department of Ecology website (Appendix 2). Feasibility refers to a subjective assessment of the potential use of a method at Cultus Lake to benefit sockeye. H = High, M = moderate, L = low, N = not feasible.

Method	Feasibility at Cultus	Description and advantages	Disadvantages
Physical treatments			
Rototilling	H	Underwater rototilling	Fragments are dispersed and may re-sprout
		Removes entire plant	Non-selective
		Treat large areas and lasts 1 to 2 years	Can disturbs sediments and sockeye spawning areas
Bottom barriers	H	Kills weeds by blocking light	Require routine maintenance to clear sediment and plants that grow through
		Can be moved periodically (weeks)	Stems can grow around edges and up
			Non-selective
Harvesting	L	'Underwater lawn mowing'	Largely cosmetic and temporary (weeks)
		Biomass is removed	No benefit to sockeye
Hand pulling	M	'Like pulling weeds from the garden'	Small scale
		Selective and may not disturb spawning areas	
Diver dredging	M	Diver with a suction dredge	Small scale and expensive
		Selective	
Chemical treatments			
2,4-D	L	Selective for EWM	Water quality concerns
Fluridone	L	Somewhat selective for EWM	Water quality concerns
Biological treatments			
Milfoil weevil (*Euhrychiopsis lecontei*)	N	Feeds on and kills EWM, selective	Largely untested
		Native to British Columbia (documented at Cultus?)	Only controls stems for Aug-Sept
Cricotopus myriophylli (midge)	N	Larvae eat meristem, selective to milfoil genera (EWM or native)	Largely untested
		Native to British Columbia (documented at Cultus?)	
		Associated with EWM declines in BC	
Grass carp	N	Herbivorous carp	Eats all aquatic macrophytes

Appendix 2. Websites with useful information on Eurasian watermilfoil.

Site	URL	Description
Washington Department of Ecology	http://www.ecy.wa.gov/programs/wq/links/plants.html	Excellent reference for EMW ecology and control
Texel	http://www.texel.qc.ca/html/english/applications/agrotextiles/weed_barriers.php	Manufacturer of bottom barriers
Sea Grant Nonindigenous Species site	http://www.sgnis.org/update/eurwat.htm	Reference list for milfoil publications and links for pdfs
Columbia Shuswap Regional District	http://www.csrd.bc.ca/works/milfoil.htm	Description of their control program and contact info

Appendix 3. Contact information for Eurasian watermilfoil control at Cultus Lake.

Contact	Organization	Contact for	Tel #	email
Jim Wiebe	BC Parks	BC Parks participation in program	(604) 824-2314	Jim.Wiebe@gems7.gov.bc.ca
Greg Armour	Okanagan-Basin Water Board	Rototiller availability and costs Has experience with milfoil programs	(250) 550-3773	Greg.Armour@nord.ca
Hamish Kassa	Columbia Shuswap Regional District	Rototiller availability Has experience with milfoil programs	(250) 833-7911	hkassa@csrd.bc.ca
Robert Truelson	Department of Environment, Government of Yukon	Authored summary reports for EWM control programs and surveys at Cultus during the 1980-90s	(867) 667-3217	bob.truelson@gov.yk.ca