Rocky Mountain ridged mussel (*Gonidea angulata*) project:

Interim report on juvenile recruitment, host fish field sampling, and the impact of rototilling against Eurasian watermilfoil (*Myriophyllum spicatum*).

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Photo: Roxanne Snook

On behalf of the University of British Columbia – Okanagan,

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Introduction

The Rocky Mountain ridged mussel (*Gonidea angulata*) is COSEWIC listed as endangered (COSEWIC 2010) and SARA listed as a Species of Concern (Fisheries and Oceans Canada, 2010) in Canada. It is only found within the Okanagan Valley in British Columbia (Stanton *et al.* 2012), and the province has red-listed it with a S1 status (BC Conservation Data Centre 2012a). However, very little is known about the biology of this mussel in general (reviewed in Jepsen *et al.* 2010b, COSEWIC 2010, Fisheries and Oceans Canada 2010, BC Conservation Data Centre 2012b). Even less is known about its current status and the threats to its survival in BC (see discussions in COSEWIC 2010, Fisheries and Ocean Canada 2010, BC Conservation Data Centre 2012a,b, Stanton *et al.* 2012).

Due to the lack of knowledge about Rocky Mountain ridged mussel, the *Species at Risk* Management Plan for the mussel (Fisheries and Oceans Canada 2010) emphasizes the importance of doing research to provide the necessary information to help protect the mussel and contribute to its recovery in Canada. Specifically, it states that "[p]riority research [on the mussel] will focus on life history and host fish(s), habitat mapping, clarification of threats to both the species and the host fish(s), and inventory throughout the species range in Canada" (p. 33 in Fisheries and Oceans Canada 2010). Among the potential threats against this mussel in the Okanagan Valley are in-stream development, historic channelization of the Okanagan River, water flow alterations, introduced species, host species availability, land-use pollution, activities with direct harmful impact, and climate change (see COSEWIC 2010, Fisheries and Oceans Canada 2010). Thus, the research efforts on the mussel should focus on understanding its basic biology and these threats.

One of the most important facts to determine when evaluating a freshwater mussel population is whether juvenile mussels are being recruited into the population (see e.g. review in Larsen 1997, discussion in Stanton *et al.* 2012). The reason for this is that adults are known to survive even if they cannot reproduce and/or juveniles cannot survive (reviewed in e.g. Larsen 1997, Jepsen 2010a, Stanton *et al.* 2012). Since freshwater mussels, including Rocky Mountain ridged mussel, are relatively long lived (reviewed in e.g. Larsen 1997, Jepsen 2010a,b) populations can persist for a long period of time without reproduction and/or juvenile recruitment (reviewed in e.g. Larsen 1997, Jepsen 2010a). Thus, if only investigating adult mussels one might come to the conclusion that the mussel population is healthy, despite environmental factors having eliminated reproduction and/or recruitment. Although it is known

that Rocky Mountain ridged mussels reproduce within the Okanagan Valley (Fisheries and Oceans Canada 2010, Stanton *et al.* 2012), very little is known about the recruitment of juveniles into the population (Lora Nield *Pers. com.*). The few surveys that have been undertaken have only revealed larger mussels (Stanton *et al.* 2012). Thus, it is essential to investigate whether recruitment is occurring in the Okanagan Valley, and whether the recruitment is occurring at a level sufficient to sustain the population. If this is not the case, a juvenile stocking program may be necessary (for examples, see reviews in Neves 2004, Thomas *et al.* 2010).

Among the potential threats to Rocky Mountain ridged mussel in the Okanagan Valley is the lack of fish host availability (COSEWIC 2010, Fisheries and Oceans Canada 2010). A lack of fish hosts may, among other things, be the result of invasive fish species displacing suitable native host fish from the mussel beds (COSEWIC 2010, Fisheries and Oceans Canada 2010). From the US it is known that the mussel's glochidia only can metamorphose into juvenile mussels on a few host species (Spring Rivers 2007, O'Brien *et al.* 2013). However, the host is unknown in Canada, although limited field sampling suggests that both Northern Pikeminnow (*Ptychochelius oregonensis*) and Prickly sculpin (*Cottus asper*) may be host fish (Stanton *et al.* 2012). Without knowing the host for the mussel, it is impossible to determine whether the lack of fish host availability is a threat to the mussel in the Okanagan Valley. Similarly, it is impossible to determine if invasive fish are a threat to the mussel by displacing suitable host fish from the mussel beds.

Another potential threat to Rocky Mountain ridged mussel in the Okanagan Valley is associated with the invasive plant Eurasian watermilfoil (*Myriophyllum spicatum*). The species may potentially be a threat, in itself, as it alters the littoral habitat (COSEWIC 2010, Fisheries and Canada 2010). Thus, treating against this plant may be beneficial to the mussel. However, one of the treatment methods in use encompasses rototilling the substrate (for details, see Dunbar 2009). This method may be a threat to the mussel (COSEWIC 2010, Fisheries and Oceans Canada 2010), as it may directly crush the mussel or bury it, which is known to negatively impact the mussel (Krueger *et al.* 2007). Thus, treating against watermilfoil may be positive or negative for the mussel, depending on the methods used.

The BC Ministry of Forests, Lands and Natural Resource Operations, the BC Ministry of Environment, and the University of British Columbia - Okanagan have launched a research project on Rocky Mountain ridged mussel. The overall goal of the project is to improve the management of this endangered species. This project includes research on, among other things, these three areas related to the conservation the mussel in the Okanagan Valley: 1) Determining whether Rocky Mountain ridged

mussel recruitment is occurring and is sufficient to maintain the population. 2) Identifying the host fish species for Rocky Mountain ridged mussel. 3) Evaluating the impact of rototilling against Eurasian watermilfoil on Rocky Mountain ridged mussel. To achieve these goals a variety of methods, including surveys and fish sampling, will be used.

Methods

Recruitment of juvenile Rocky Mountain ridged mussels

The goal of the surveys on juvenile recruitment is to determine whether juvenile Rocky Mountain ridged mussels are being recruited in the Okanagan Valley, where this recruitment is occurring, and if is sufficient to maintain the mussel population. To achieve the two former goals it is sufficient to detect juveniles. However, to determine whether recruitment is occurring at a sufficient rate is more complicated. For the Eastern Pearlshell (*Margaritifera margaritifera*), it has been suggested that a healthily recruiting population contains 20 % of mussels under 20 years old and some under 10 years old (Young *et al.* 2001). However, since Rocky Mountain ridged mussels live shorter than pearlshells (see reviews in e.g. Larsen 1997, COSEWIC 2010, Fisheries and Oceans Canada 2010, Jepsen *et al.* 2010a,b) these ages will have to be adjusted. To determine the approximate age of Rocky Mountain ridged mussels in the Okanagan Valley, the number of growth rings in the mussels shells will be counted (see e.g. review in Larsen 1997, Ruppert *et al.* 2004). Based on the maximum age of the mussel, the percentage of mussels that need to be under a certain age and size to maintain a healthy population will be established. These methods are adapted from Larsen and Hartvigsen (1999).

To maximize the likelihood of finding juveniles and due to the importance of high density sites to overall population numbers, survey sites were limited to sites with a substantial number of adult Rocky Mountain ridged mussels. Based on these selection criteria nine sites were selected and surveyed (see Table 1 and Figure 1).

Table 1 Overview of locations for Rocky Mountain ridged mussel juvenile recruitment surveys.

Location	Town	Waterbody	UTM
Kin Beach, Vernon Arm	Vernon	Okanagan Lake	11U 332244 5568992
Peach Orchard Beach	Summerland	Okanagan Lake	11U 308430 5498588
Dog Beach	Summerland	Okanagan Lake	11U 308563 5498378
Kinsman Park	Summerland	Okanagan Lake	11U 308458 5497453
Pumphouse	Summerland	Okanagan Lake	11U 308469 5497360
South Okanagan Sailing Association	Summerland	Okanagan Lake	11U 308569 5497093
Three Mile Beach, Naramata Benchlands	Penticton	Okanagan Lake	11U 313605 5490390
Vaseux Campsite	Oliver	Vaseux Lake	11U 316027 5463628
Downtown Oliver	Oliver	Okanagan River	11U 314292 5451415

Detecting juvenile freshwater mussels is difficult due to their small size (reviewed in e.g. Larsen and Hartvigsen 1997, Stanton *et al.* 2012) and the fact that they are typically buried in the substrate (reviewed in e.g. Larsen 1997, Strayer *et al.* 2004, Jepsen 2010a). To maximize the chance of finding a representative age distribution of Rocky Mountain ridged mussels, transect surveys were undertaken at each location. The transects were placed at regular intervals throughout the mussels beds and ran from the shoreline to the end of the mussel beds. Both visible and buried mussels were measured as a proxy for age. The buried mussels were detected by removing rocks from within the transects and carefully fanning away the rest of the substrate. Any younger mussels found, were aged by counting growth rings (see review of methods in e.g. Larsen 1997, Ruppert *et al.* 2004). Over 100 mussels were measured at each site, with the exception of a few low density sites. In addition, the approximate

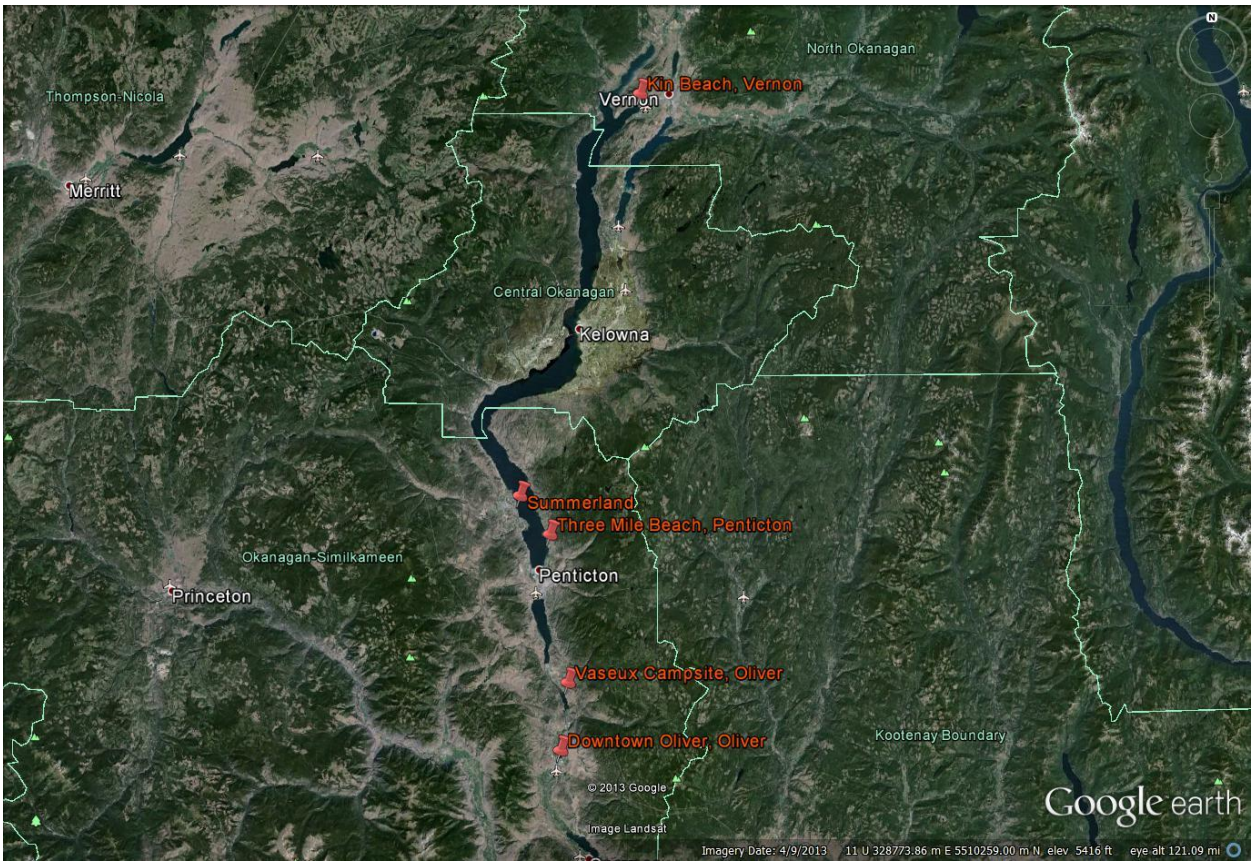

Figure 1 Overview of locations for Rocky Mountain ridged mussel juvenile recruitment surveys.

maximum age of the mussel in the Okanagan was established by estimating the age of at least 25 older mussels at each of two of the high density sites (Dog Beach and Kinsman Park, Summerland). These methods are adapted from Larsen and Hartvigsen (1997), and Mageroy (2005). All surveys were completed by snorkelers.

Field data on Rocky Mountain ridged mussel fish host use

The goal of collecting field data on Rocky Mountain ridged mussel fish host use is twofold: 1) To suggest which fish hosts Rocky Mountain ridged mussels use. This will be achieved by collecting fish during the period that the mussel releases conglutinates. The fish gills will be investigated with respect

to prevalence and intensity, which will show which fish are exposed to the mussel's glochidia the most. However, as mussel glochidia can attach to unsuitable host species (reviewed in e.g. Larsen 1997, discussed in e.g. O'Brien *et al.* 2013), such findings can only suggest potential host species. Glochidial growth will only be expected to occur on suitable host fish and will provide a stronger suggestion with respect to the mussel's host use. This growth will be determined by comparing the size of the glochidia on the fish gills to the size of glochidia in the conglutinates released by the mussel. 2) To provide information necessary to complete an experiment infecting fish with Rocky Mountain ridged mussel glochidia. Although glochidial growth would strongly suggest which fish species serve as hosts for the mussel, only the observation of glochidia metamorphosing into juvenile mussels can confirm such field findings (see Spring Rivers 2007, O'Brien *et al.* 2013). Thus, it will be necessary to complete an experiment for such a confirmation. In designing such an experiment, the field data on prevalence, intensity and glochidial growth is important in determining which fish species to include in the experiment. In addition, it is important to gain some understanding of the length of the infection period. This will be achieved by comparing prevalence and intensity to conglutinate observation rates, as conglutinate rates are known to occur in peaks in the Okanagan Valley (Stanton *et al.* 2012). Maximal prevalence and intensity is expected to lag behind maximal conglutinate release, and the lag should suggest the approximate length of the infection period.

All data on Rocky Mountain ridged mussel fish host use were collected from Kinsman Park and Dog Beach in Summerland, Okanagan Lake. These sites were selected to maximize prevalence and intensity, as they have two of the largest populations of the mussel in the Okanagan Valley.

The BC Ministry of Forests, Lands, and Natural Resource Operations had a contractor survey these sites for the release of Rocky Mountain ridged mussel conglutinates from the middle of May until conglutinate release approached minimal levels, which occurred in the beginning of July. University of British Columbia - Okanagan personnel also completed supplementary surveying of conglutinate releases at the same sites during the same time period. The results of these surveys were used to determine the rates of conglutinate release and when fish should be collected from the lake.

BC Ministry of Forests, Lands, and Natural Resource Operations, BC Ministry of Environment, and University of British Columbia – Okanagan personnel took part in the fish collection. The collection took place approximately once a week between June 17th and July 12th, 2013. The fish were collected using minnow traps and seines. Traps were set over night. The fish were euthanized using buffered MS-222 and preserved in 70 % ethanol. Subsequently, the fish gills will be examined to determine mean

prevalence, intensity and Rocky Mountain ridged mussel glochidial size for each species. In addition, conglutinates were sampled from 5 mussels each at Dog Beach and Kinsman park. These samples will be analyzed and a sub-sample of glochidia will be measured to determine the initial size of glochidia at the time of infection.

Effects of Eurasian watermilfoil rototilling on Rocky Mountain ridged mussel

The overall goal of the investigation into treatment for Eurasian watermilfoil is to determine whether rototilling has a negative impact on Rocky Mountain ridged mussel. This impact on the mussel will be evaluated using two methods: 1) Locations that are being or have been rototilled against Eurasian watermilfoil and are potential Rocky Mountain ridged mussel sites will be surveyed to evaluate the extent of the potential conflict between conservation of the mussel and rototilling against the plant. 2) Evaluation of the direct effect of rototilling on Rocky Mountain ridged mussel by the use of an 'artificial mussel' experiment. The comparison studies, suggested in the original methodology for this project (Mageroy 2013), had to be abandoned due to the low number of rototilling locations found during surveying (see results).

Surveys for Rocky Mountain ridged mussel in Eurasian watermilfoil rototilling polygons

The overall goal of these surveys is to determine the geographic scope of the potential conflict between Rocky Mountain ridged mussel conservation and rototilling against Eurasian watermilfoil. The surveys will be used to determine the presence or absence of both live mussels and empty shells. They will only be performed in watermilfoil polygons that are or have been rototilled, since harvesting (for details, see Dunbar 2009) is likely to have a positive impact on the mussel (see introduction).

Survey sites were selected in consultation with Lora Nield, BC Ministry of Forests, Lands, and Natural Resource Operations, and James Littley, Ian Horner, Dave Caswell, and Pat Field, Okanagan Basin Water Board. The sites were selected based on the proximity of Eurasian watermilfoil rototilling polygons to findings of Rocky Mountain ridged mussel (both live mussels and empty shells), perceived

Figure 2 Overview of locations for Eurasian watermilfoil rototilling surveys.

habitat suitability for the mussel, previous survey efforts, ease of access, and current and past watermilfoil treatment practices. Based on these selection criteria, 40 Eurasian watermilfoil rototilling polygons were selected (see Table 2 in Results and Figure 2).

The surveys were completed by snorkelers. They were conducted using a grid pattern to cover the Eurasian watermilfoil rototilling polygons as thoroughly as possible, from the shoreline until the depth was too great to see the bottom. For each survey, the numbers of live Rocky Mountain ridged mussels and empty shells were recorded.

Direct effects of Eurasian watermilfoil rototilling on artificial Rocky Mountain ridged mussels

The goal of this experiment is to directly evaluate the impact of Eurasian watermilfoil rototilling on Rocky Mountain ridged mussel. However, the BC Ministry of Forests, Lands, and Natural Resource Operations wish to minimize the sacrifice of live mussels when determining the impact of rototilling on the mussel. Thus, artificial mussels will be exposed to rototilling to determine whether this treatment crushes and/or buries the mussels.

Sites for the experiment will be selected based on the substrate being representative of Rocky Mountain ridged mussel habitat and the possibility of placing the mussels in two adjacent areas, the one scheduled for rototilling and the other not scheduled for rototilling.

To test for the suitability of using 'artificial Rocky Mountain ridged mussels' to evaluate the impact of rototilling on the mussel, a small number of live mussels (max. 30) will be sacrificed to mechanically determine the strength of the mussel. Strength tests will be performed along the length, height, and width of the mussels. 'Artificial mussels' will be produced by collecting empty shells in good condition, preserving them, filling them with an appropriate material, gluing them shut, and mechanically determining their strength compared to the live mussels. The preservation, filling, and gluing methods will be adjusted to achieve strengths comparable to the live mussels.

Once the appropriate methodology for producing 'artificial Rocky Mountain ridged mussels' has been finalized, 200 artificial mussels will be produced and painted in a highly visible color. The 200 artificial mussels will be placed in two 100 m^2 areas. One of the areas will be rototilled while the other will be maintained as a control. The areas will be checked for crushed ‘artificial mussels’. In addition, they will be checked for the total number of mussels recovered to estimate the number of ‘artificial mussels’ buried by rototilling. The areas will be surveyed by snorkelers.

Results

Recruitment of juvenile Rocky Mountain ridged mussels

Overall, we measured a total of 1049 Rocky Mountain ridged mussels as a part of our juvenile recruitment surveys and 53 mussels when trying to establish maximum age among the mussels. The youngest mussels found were two years old, while the oldest mussels were estimated to be 30 years old. The shortest mussel found was 16 mm, while the longest was 120 mm. 1.3 %, 5.3 %, and 23.0 % of the mussels were 3, 6 or 10 years and younger, respectively. The reduction in growth among seven year old mussels (see Figure 3a) suggests that these mussels mature when they are approximately at this age (see discussion of the relationship between growth and sexual maturation in Larsen 1997). If we make this assumption, the mussels 6 years old and younger make up the juvenile percentage of the population. Overall, 23.7 % of the mussels were found buried in the substrate, while 77.6 % of juveniles were buried. See Figure 2a for the overall length distribution. However, there were great differences in youngest mussel found, percentage buried, growth (see Figure 3) and length distributions (Figure 4) among the different surveying locations.

Kin Beach, Vernon, Vernon Arm, Okanagan Lake: A total of 106 Rocky Mountain ridged mussels were measured. The youngest mussel was two years old, and the mussels ranged in size from 21 to 112 mm in length. 0.9 %, 1.9 %, and 2.8 % of the mussels were 3, 6 or 10 years and younger, respectively. 24.4 % of the mussels were buried. See Figure 3b for growth curve and Figure 4b for length distribution. Note that for some transects, the buried mussels could not be investigated due to silt from digging resulting in too low a visibility.

Peach Orchard Beach, Summerland, Okanagan Lake: A total of 22 Rocky Mountain ridged mussels were measured. The youngest mussel was five years old, and the mussels ranged in size from 45 to 93 mm in length. 0.0 %, 9.1 %, and 27.3 % of the mussels were 3, 6 or 10 years and younger, respectively. 22.7 % of the mussels were buried. See Figure 3c for growth curve and Figure 4c for length distribution.

Dog Beach, Summerland, Okanagan Lake: A total of 111 Rocky Mountain ridged mussels were measured. The youngest mussel was two years old, and the mussels ranged in size from 19 to 96 mm in length. 2.8 %, 9.4 %, and 26.2 % of the mussels were 3, 6 or 10 years and younger, respectively. 23.4 % of the mussels were buried. See Figure 3d for growth curve and Figure 4d for length distribution.

Kinsman Park, Summerland, Okanagan Lake: A total of 194 Rocky Mountain ridged mussels were measured. The youngest mussel was three years old, and the mussels ranged in size from 35 to 100 mm in length. 0.5 %, 2.1 %, and 27.3 % of the mussels were 3, 6 or 10 years and younger, respectively. 22.3 % of the mussels were buried. See Figure 3e for growth curve and Figure 4e for length distribution. Note that for some transects, the buried mussels could not be investigated due to silt from digging resulting in too low a visibility.

Pump House, Summerland, Okanagan Lake: A total of 111 Rocky Mountain ridged mussels were measured. The youngest mussel was six years old, and the mussels ranged in size from 61 to 104 mm in length. 0.0 %, 0.9 %, and 12.6 % of the mussels were 3, 6 or 10 years and younger, respectively. 19.8 % of the mussels were buried. See Figure 3f for growth curve and Figure 4f for length distribution. Note that for some transects, the buried mussels could not be investigated due to silt from digging resulting in too low a visibility.

South Okanagan Sailing Association, Summerland, Okanagan Lake: A total of 64 Rocky Mountain ridged mussels were measured. The youngest mussel was four years old, and the mussels ranged in size from 34 to 96 mm in length. 0.0 %, 1.7 %, and 16.7 % of the mussels were 3, 6 or 10 years and younger, respectively. 2.2 % of the mussels were buried. See Figure 3g for growth curve and Figure 4g for length distribution. Note that for some transects, the buried mussels could not be investigated due to silt from digging resulting in too low a visibility.

Three Mile Beach, Naramata Benchlands, Penticton, Okanagan Lake: A total of 198 Rocky Mountain ridged mussels were measured. The youngest mussel was two years old, and the mussels ranged in size from 16 to 95 mm in length. 3.6 %, 15.7 %, and 40.0 % of the mussels were 3, 6 or 10 years and younger, respectively. 31.8 % of the mussels were buried. See Figure 3h for growth curve and Figure 4h for length distribution.

Vaseux Campsite, Vaseux Lake: A total of 138 Rocky Mountain ridged mussels were measured. The youngest mussel was six years old, and the mussels ranged in size from 59 to 120 mm in length. 0.0 %, 0.8 %, and 20.2 % of the mussels were 3, 6 or 10 years and younger, respectively. See Figure 3i for

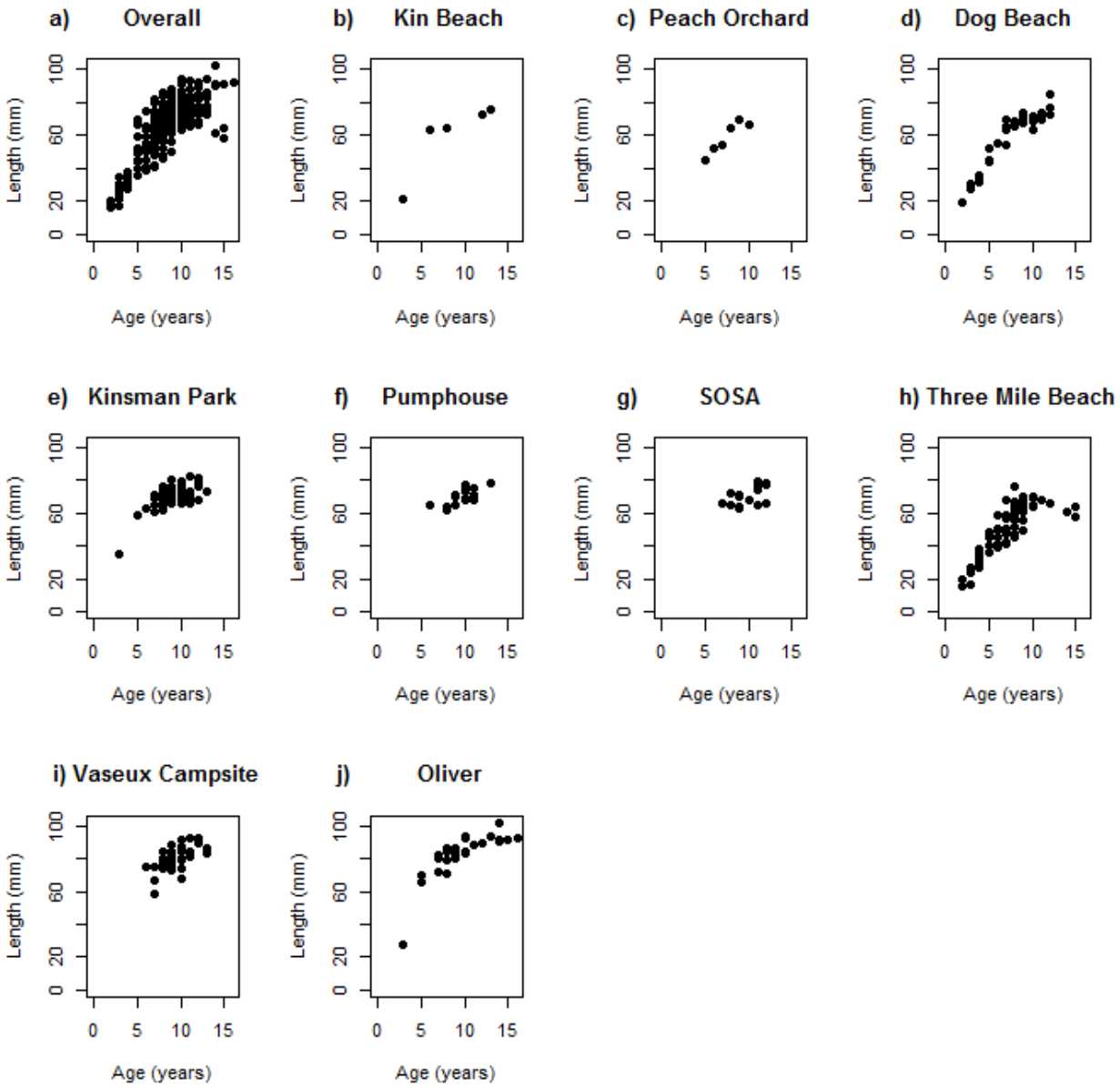

Figure 3 Growth of young Rocky Mountain ridged mussels. Growth of the mussels overall and at individual locations. The length of different age classes is considered a proxy for mussel growth.

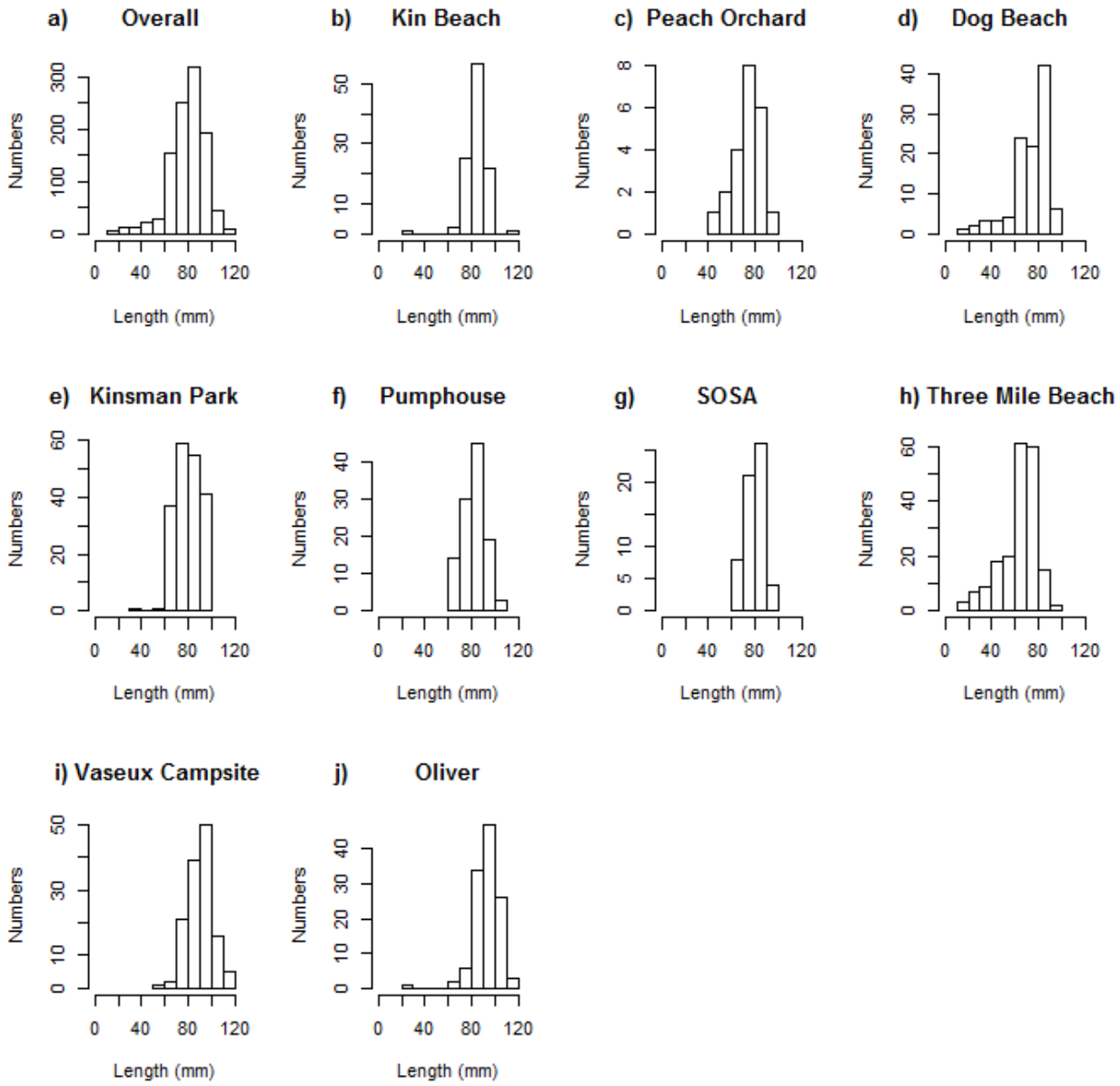

Figure 4 Length distribution of Rocky Mountain ridged mussels. Length distribution overall and at individual locations. Note that at many of the locations the buried mussels could only be partially surveyed (b, e, f, and g) or not surveyed at all (i and j).

growth curve and Figure 4i for length distribution. Note that for this location, the buried mussels could not be investigated due to silt from digging resulting in too low a visibility.

Pedestrian bridge to Fairview Rd., Oliver, Okanagan River: A total of 116 Rocky Mountain ridged mussels were measured. The youngest mussel was three years old, and the mussels ranged in size from 28 to 116 mm in length. 0.8 %, 2.5 %, and 16.0 % of the mussels were 3, 6 or 10 years and younger, respectively. See Figure 3j for growth curve and Figure 4j for length distribution. Note that for this location, with the exception of a few quadrants, the buried mussels could not be investigated due to the high current.

Field data on Rocky Mountain ridged mussel fish host use

A total of 290 fish were caught between June 17th and July 12th, 2013. This included 100 sculpin (*Cottus* spp.), 84 lake whitefish (*Coregonus clupeaformis*), 28 longnose dace (*Rhinichthys cataractae*), 22 redside shiners (*Richardsonius balteatus*), 19 lake chub (*Couesius plumbeus*), 15 pikeminnow (*Ptychocheilus oregonensis*), 11 suckers (*Catostomus* spp.), 6 yellow perch (*Perca flavescens*), 3 leopard dace (*Rhinichthys falcatus*), and 2 common carp (*Cyprinus carpio*). These fish have not yet been analyzed for Rocky Mountain ridged mussel glochidial infection.

Effects of Eurasian watermilfoil rototilling on Rocky Mountain ridged mussel

Survey results for Rocky Mountain ridged mussel in Eurasian watermilfoil rototilling polygons

Overall, live Rocky Mountain ridged mussels were found in or associated with 10 out of 40 Eurasian watermilfoil rototilling polygons that were surveyed (see Table 1 and Figures 1-8 in the Appendix). Out of these polygons, four are still being rototilled. In addition, we found shells of the mussel in another two polygons. These two polygons are not being rototilled currently.

Table 2 Overview of Rocky Mountain ridged mussel surveys in Eurasian watermilfoil rototilling polygons.

Polygon #	Lake	Location	Start UTM	Stop UTM	Live RMRM	Shells of RMRM	Last Rototilled	Current Watermilfoil Treatment
20	Osoyoos	Copper Roof Row, Osoyoos	11U 316105 5437807	11U 316066 5437919	0	20	2009	Harvesting
21	Osoyoos	Copper Roof Row, Osoyoos	11U 316066 5437919	11U 316044 5437947	0	4	2009	Harvesting
22	Osoyoos	Lakehead Campsite, Osoyoos	11U 315875 5438038	11U 315582 5438406	1	0	2012	Harvesting and Rototilling
23	Osoyoos	Lakehead Campsite, Osoyoos	11U 315582 5438406	11U 315484 5438723	0	0	2012	Harvesting and Rototilling
24	Osoyoos	Lakehead Campsite, Osoyoos	11U 315484 5438723	11U 315502 5438749	0	0	2012	Harvesting and Rototilling
25	Osoyoos	Lakehead Campsite, Osoyoos	11U 315502 5438749	11U 315629 5438872	0	0	2012	Harvesting and Rototilling
26	Osoyoos	Lakehead Campsite, Osoyoos	11U 315629 5438872	11U 315732 5438974	0	0	2010	Harvesting
27	Osoyoos	Lakehead Campsite, Osoyoos	11U 315732 5438974	11U 315925 5438942	1	0	2010	Harvesting
28	Osoyoos	Lakehead Campsite, Osoyoos	11U 315925 5438942	11U 316102 5438952	8	1	2010	Harvesting
46	Osoyoos	Hole Bay, Osoyoos	11U 321641 5431187	11U 321562 5431245	0	0	2011	Harvesting and Rototilling
47	Osoyoos	Hole Bay, Osoyoos	11U 321656 5431137	11U 321641 5431187	0	0	2011	Harvesting and Rototilling
48	Osoyoos	Hole Bay, Osoyoos	11U 321718 5430922	11U 321634 5431018	0	0	2012	Harvesting and Rototilling
49	Osoyoos	Hole Bay, Osoyoos	11U 321919 5430754	11U 321714 5430860	0	0	2012	Harvesting and Rototilling
50	Skaha	Beaches, Okanagan Falls	11U 312787 5469243	11U 312922 5469283	13	1	2003	Harvesting
51	Skaha	Beaches, Okanagan Falls	11U 312951 5469344	11U 313088 5469297	0	0	2003	Harvesting
52	Skaha	Beaches, Okanagan Falls	11U 313163 5469332	11U 313373 5469490	3	1	2003	Harvesting
53	Skaha	Lakeside Ct., Penticton	11U 313192 5478150	11U 313104 5478692	2	28	2003	Harvesting
55	Skaha	Skaha Beach, Penticton	11U 312922 5480918	11U 312919 5480780	0	0	2012	Rototilling
56	Skaha	Skaha Beach, Penticton	11U 312413 5481036	11U 312922 5480918	0	0	2012	Rototilling
57	Skaha	Skaha Beach, Penticton	11U 312253 5481022	11U 312413 5481036	0	0	2012	Rototilling

Table 2 Continued Overview of Rocky Mountain ridged mussel surveys in Eurasian watermilfoil rototilling polygons.

Polygon #	Lake	Location	Start UTM	Stop UTM	Live RMRM	Shells of RMRM	Last Rototilled	Current Watermilfoil Treatment
58	Skaha	Sudbury Beach, Penticton	11U 311819 5480974	11U 312056 5480999	0	0	2012	Rototilling
59	Skaha	Airport Beach, Penticton	11U 311588 5480986	11U 311819 5480974	0	0	2012	Rototilling
60	Skaha	Airport Beach, Penticton	11U 311223 5480922	11U 311256 5480930	0	0	2012	Rototilling
61	Skaha	Airport Beach, Penticton	11U 310997 5480836	11U 311223 5480922	0	0	2012	Rototilling
62	Okanagan	Ironman Start Beach, Penticton	11U 311845 5486542	11U 311890 5486654	0	0	Unknown	Rototilling
63	Okanagan	Penticton Marina, Penticton	11U 312661 5486868	11U 312955 5486941	0	0	2012	Rototilling
64	Okanagan	Rotary Beach, Summerland	11U 308396 5497948	11U 308571 5498316	656	531	1993	None
91	Okanagan	Casa Loma, West Kelowna	11U 317592 5525622	11U 317668 5525831	1	0	2008	Rototilling
92	Okanagan	Casa Loma, West Kelowna	11U 317957 5526175	11U 317940 5526591	0	0	2012	Rototilling
109	Okanagan	Kin Beach, Vernon	11U 332558 5568891	11U 332508 5568953	1	1	2012	Harvesting and Rototilling
110	Okanagan	Kin Beach, Vernon	11U 332750 5568568	11U 332558 5568891	0	0	2012	Harvesting and Rototilling
111	Okanagan	Kin Beach, Vernon	11U 332820 5568385	11U 332750 5568568	0	0	2012	Harvesting and Rototilling
112	Okanagan	Kin Beach, Vernon	11U 332837 5568349	11U 332820 5568385	0	0	2012	Harvesting and Rototilling
113	Okanagan	Kin Beach, Vernon	11U 332920 5568045	11U 332837 5568349	0	0	2012	Harvesting and Rototilling
114	Okanagan	Kin Beach, Vernon	11U 332780 5567909	11U 332920 5568045	0	0	2012	Harvesting and Rototilling
117	Okanagan	Okanagan Landing, Vernon	11U 331763 5567484	11U 332057 5567563	1	0	2012	Harvesting and Rototilling
118	Okanagan	Okanagan Landing, Vernon	11U 331576 5567402	11U 331763 5567484	0	0	2012	Harvesting and Rototilling
119	Okanagan	Okanagan Landing, Vernon	11U 331521 5567380	11U 331576 5567402	0	0	2012	Harvesting and Rototilling
199	Skaha	Sudbury Beach, Penticton	11U 312056 5480999	11U 312253 5481022	0	0	2012	Rototilling
200	Skaha	Airport Beach, Penticton	11U 311256 5480930	11U 311588 5480986	0	0	2012	Rototilling

Direct effects of Eurasian watermilfoil rototilling on artificial Rocky Mountain ridged mussels

This experiment has not been completed yet.

Discussion

Overall for the project, most of the data collection has been completed, but few of the analyses have. Thus, it is too early to draw many conclusions with respect to Rocky Mountain ridged mussel juvenile recruitment, and especially host fish use and the impact of rototilling against Eurasian watermilfoil. One of the exceptions to this is that we can conclude that juveniles have been recruited into the mussel populations relatively recently. Similarly, we can conclude that the conflict between rototilling against watermilfoil and conservation of the mussel is rather limited in its geographical scope, since mussels were only found in four polygons that are currently being rototilled.

Recruitment of juvenile Rocky Mountain ridged mussels

It is good news that juvenile Rocky Mountain ridged mussels as young as two or three years old were found at a majority of the locations surveyed, and mussels seven years or younger were found at all the locations (see Figure 3). These findings show that juveniles have been recruited into all of these populations fairly recently. It is also important to consider that juvenile mussels are very difficult to find due to their small size (reviewed in e.g. Larsen and Hartvigsen 1997, Stanton *et al.* 2012) and the fact that they are typically buried in the substrate (reviewed in e.g. Larsen 1997, Strayer *et al.* 2004, Jepsen 2010a). Thus, the youngest ages are likely to be overestimates. Similarly, the percentages of young mussels are likely to be underestimates.

The youngest Rocky Mountain ridged mussel found, percentages of young mussels, and length distributions (see Figure 4) vary greatly between sites. Based on these findings it seems that Dog Beach

(Figures 3d and 4d) and Three Mile Beach (Figures 3h and 4h) house the youngest mussel populations among the locations we surveyed, which suggest that they should be considered of special importance to the conservation of the mussel in the Okanagan Valley. On the other hand, it seems that Kin Beach (Figures 3b and 4b) house the oldest population, which suggests that it may be the most threatened population among the ones we surveyed. The other locations seem to house populations that are between these two extremes in their age distributions.

However, certain considerations have to be taken when discussing these conclusions. Many of the locations with higher youngest ages and lower percentages of young Rocky Mountain ridged mussels could not be surveyed or only partially surveyed for buried mussels, due to poor visibility when digging or high currents. Overall, we found that 23.7 % of the mussels were buried in the substrate, while 77.6 % of juveniles were buried. This suggests that our inability to complete surveys for buried mussels may explain why we didn't find more young mussels. Alternatively, the silt may not only have prevented us from finding young mussels, but it may also have prevented young mussels from being recruited into the population at these locations. This may be the case since juveniles of freshwater mussels have been found to be more sensitive to siltation than adults (e.g. reviewed in Larsen 1997) and since Rocky Mountain ridged mussel typically do not favor too high a level of siltation (see reviews in COSEWIC 2010, Fisheries and Canada 2010, Jepsen 2010a). With this in mind, it is interesting to note that Dog Beach and Three Mile Beach are the two location most exposed to wave action of any of the locations we surveyed (*Pers. Obs.*).

A further consideration has to be taken with respect to the length distributions of Rocky Mountain ridged mussels. It seems that the mussels grow faster in the southern Okanagan (Oliver and Vaseux Campsite, see Figures 3i and j, respectively) than in the northern Okanagan (Dog Beach, Kinsman Park, and Three Mile Beach, see Figures 3d, e, and h, respectively). This may be explained by the fact that the water temperatures are higher in the southern part of the valley than in the northern part (*Pers. obs.*), and freshwater mussels are known to grow faster in warmer temperatures (see review in e.g. Larsen 1997). Thus, the difference in growth rate has to be taken into consideration when comparing length distributions between the southern and northern sites. However, these differences in growth should not affect our main conclusions since they were based on differences in age between the locations.

Whether the recruitment of Rocky Mountain ridged mussel juveniles is high enough to maintain the population requires further analysis before any conclusions can be drawn.

Field data on Rocky Mountain ridged mussel fish host use

No conclusions can be drawn with respect to Rocky Mountain ridged mussel fish host use until the gills of the collected fish have been analyzed.

Effects of Eurasian watermilfoil rototilling on Rocky Mountain ridged mussel

Our surveys show the conflict between rototilling against Eurasian watermilfoil and the conservation of Rocky Mountain ridged mussel is currently rather limited in its geographical scope, since mussels were only found in four polygons that are being rototilled (see Table 2). However, the historical conflict might have been greater since we found live mussels in or associated with six of the polygons that are no longer being rototilled. In addition, we found empty shells in another two polygons that are no longer being rototilled. It is also interesting to note that mussels were found in very low numbers in these polygons, with the exception of the polygon which has been not been rototilled since approximately 1993 (Polygon 64, Rotaroy Beach, Summerland). Further, it is interesting to note that in the other polygons, the mussels were often found right along the edges (see Figures 2, 3, and 6 in the Appendix) of the rototilling area, under docks (see Figures 3 and 6 in the Appendix) or close to shore (see Figures 1, 2, 3, 7, and 8 in the Appendix). These are all sites that could not have been or are unlikely to have been rototilled.

No conclusions can be drawn with respect to the direct impact of rototilling against Eurasian watermilfoil on Rocky Mountain ridged mussel until the 'artificial mussel' experiment has been completed.

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References Cited

B.C. Conservation Data Centre. 2012a. *Conservation Status Report:* Gonidea angulata*.* B.C. Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed March 20, 2013).

B.C. Conservation Data Centre. 2012b. *Species Summary:* Gonidea angulata. B.C. Ministry of Environment. http://a100.gov.bc.ca/pub/eswp/ (accessed March 20, 2013).

Canadian Science Advisory Secretariat. 2011. Recovery potential assessment for Rocky Mountain ridged mussel (*Gonidea angulata*) in British Columbia*. Canadian Science Advisory Secretariat Report* **053**.

COSEWIC. 2010. *COSEWIC assessment and status report on the Rocky Mountain Ridged Mussel* Gonidea angulata *in Canada.* Committee on the Status of Endangered Wildlife in Canada. http://www.cosewic.gc.ca/eng (accessed May 22, 2013).

Fisheries and Oceans Canada. 2010. Management plan for the Rocky Mountain ridged mussel (*Gonidea angulata*) in Canada [Final]. *Species at Risk Act Management Plan Series.* Fisheries and Oceans Canada, Vancouver.

Dunbar, G. 2009. *Management Plan for Eurasian Watermilfoil (*Myriophyllum spicatum*) in the Okanagan, British Columbia*. Okanagan Basin Water Board. http://www.obwb.ca/fileadmin/docs/ (accessed June 6, 2013.)

Jepsen, S., LaBar, C. & Zarnoch, J. 2010a *Species Profile: Western Pearlshell (*Margaritifera falcata*)*. The Xerces Society. http://www.xerces.org/western-freshwater-mussels (accessed July 7, 2012).

Jepsen, S., LaBar, C. & Zarnoch, J. 2010b *Species Profile: Western Ridged Mussel (*Gonidea angulata*)*. The Xerces Society. http://www.xerces.org/western-freshwater-mussels (accessed March 20, 2013).

Krueger, K., Chapman, P., Hallock, M. & Quinn, T. 2007. Some effects of suction dredge placer mining on the short-term survival of freshwater mussels in Washington. *Northwest Science* **81**, 323-332.

Larsen, B.M. 1997 The freshwater pearl mussel (*Margaritifera margaritifera* L.): Literature review with a summary of the national and international knowledge status. *Norwegian Institute for Natural Research Scientific Report* **028**. [Translated from Norwegian.]

Larsen, B.M. & Hartvigsen, R. 1999 Methodology for field surveys and categorization of the Freshwater Pearl Mussel *Margaritifera margaritifera*. *Norwegian Institute for Natural Research Scientific Report* **037**.

Mageroy, J. 2005. *The Freshwater Pearl Mussel (*Margaritifera margaritifera *L.) in the Oselva River: A population study of a red-listed species.* Master Thesis, University of Bergen.

Mageroy, J. 2013. *Rocky Mountain Ridge Mussel Project: Methodology on Juvenile Recruitment, Host Fish Use and Eurasian Watermilfoil Treatment Impact.* Report. University of British Columbia – Okanagan, Kelowna, BC.

Neves, R. 2004 Propagation of endangered freshwater mussels in North America. *Journal of Conchology* **SP3**, 69-80.

Nield, L. 2013 *Personal communication*. Senior Ecosystems Biologist, Penticton Office, BC Ministry of Forests, Lands and Natural Resource Operations.

O'Brien, C., Nez, D., Wolf, D. & Brim Box, J. 2013. Reproductive biology of *Anodonta californiensis*, *Gonidea angulata* and *Margaritifera falcata* (Bivalvia: Unionoida) in the Middle Fork John Day River, Oregon. *Northwest Science* **87**, 59-72.

Ruppert, E.E., Fox, R.S. & Barnes, R.D. 2004. *Invertebrate Zoology: A Functional Evolutionary Approach.* Brooks/Cole-Thompson Learning, Belmont, CA.

Spring Rivers, 2007. *Reproductive Timing of Freshwater Mussels and Potential Impact of Pulsed Flows on Reproductive Success.* California Energy Commission, PIER Energy-Related Environmental Research Program. **CEC-500-2007-097**.

Stanton, L., Lauzier, R., MacConnachie, S., Nield, L., Pollard, S., Heron, J. & Davies, S. 2012 Exploratory surveys and directed studies on Rocky Mountain ridged mussel (*Gonidea angulata* Lea, 1839) in British Columbia. *Canadian Manuscript Report of Fisheries and Aquatic Sciences* **3003**.

Strayer, D.L., Downing, J.A., Haag, W.R., King, T.L., Layzer, J.B., Newton, T.J. & Nichols, S.J. 2004. Changing perspectives on pearly mussels, North America's most imperiled animals. *Bioscience* **54**, 429-439.

Thomas, G.R., Taylor J. & Garcia de Leaniz, C. 2010 Captive breeding of the endangered freshwater pearl mussel *Margaritifera margaritifera*. *Endangered Species Research* **12**, 1-9.

Young, M.R., Hastie, L.C. & al-Mousawi, B. (2001) What represents an "ideal" population profile for *Margaritifera margaritifera*? P. 35-44 in *Die Flussperlmuschel in Europa: Bestandssituation und Schutzmassnahmen.* Wasserwirtschaftsamt Hof & Albert-Ludwigs Universität Freiburg.

Appendix:

Figures showing Rocky Mountain ridged mussel finds in and associated with Eurasian watermilfoil rototilling polygons.

Figure 1 Polygon 22 Rocky Mountain ridged mussel find. The find site is in the northwestern corner of Osoyoos Lake (Lakehead Campsite, Osoyoos). The white pins and grey polygons indicate the Eurasian watermilfoil treatment polygon numbers and areas. Within the polygons, the yellow area indicates the area surveyed for the mussel. The red polygon and pin indicates the area in which mussels were found and the number of mussels found.

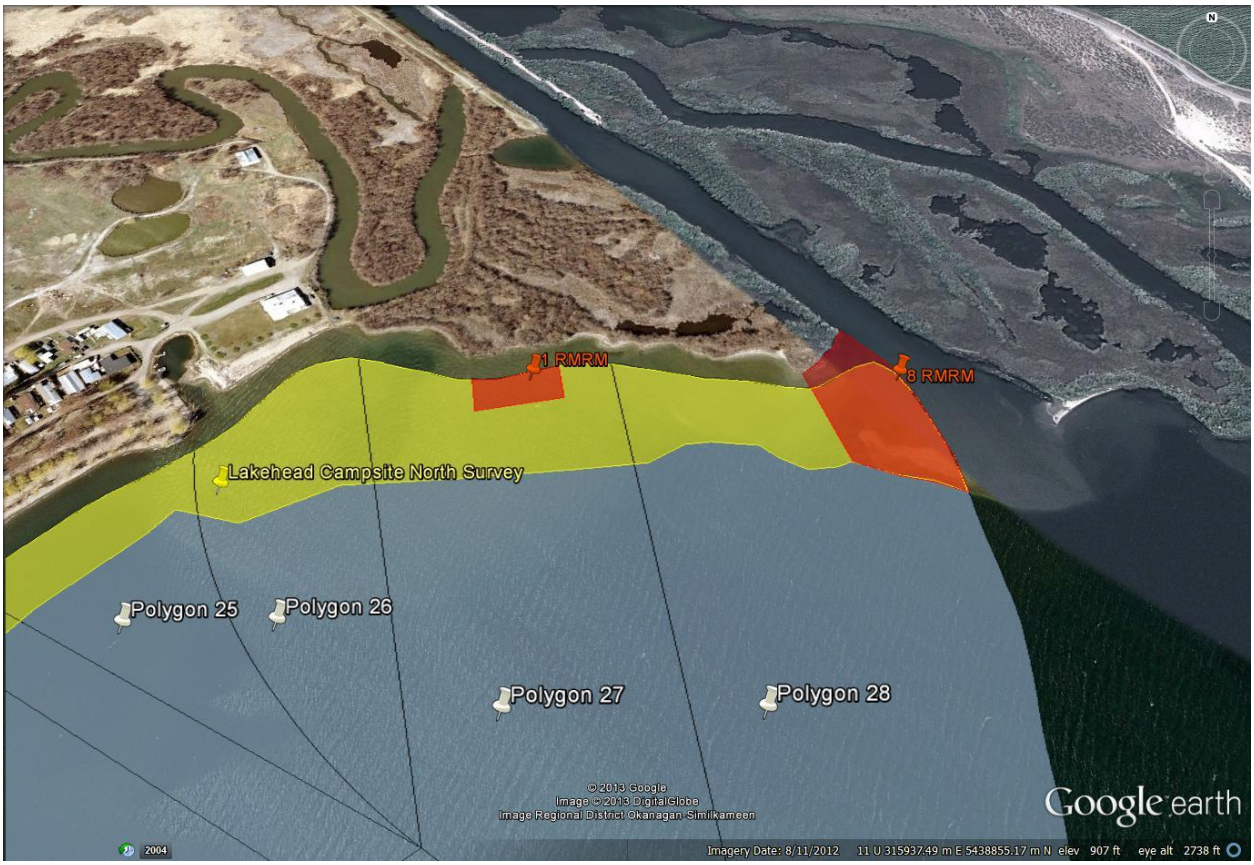

Figure 2 Polygons 27 and 28 Rocky Mountain ridged mussel finds. The find sites are at the northern end of Osoyoos Lake (Lakehead Campsite, Osoyoos). The white pins and grey polygons indicate the Eurasian watermilfoil treatment polygon numbers and areas. Within the polygons, the yellow area indicates the area surveyed for the mussel. The red polygons and pins indicate the areas in which mussels were found and the number of mussels found.

Figure 3 Polygons 50 and 52 Rocky Mountain ridged mussel finds. The find sites are at the southern end of Skaha Lake (Beaches, Okanagan Falls). The white pins and grey polygons indicate the Eurasian watermilfoil treatment polygon numbers and areas. Within the polygons, the yellow areas indicate the areas surveyed for the mussel. The red polygons and pins indicate the areas in which mussels were found and the number of mussels found.

Figure 4 Polygon 53 Rocky Mountain ridged mussel find. The find site is towards the northern end of the eastern shore of Skaha Lake (Lakeside Ct., Penticton). The white pin and grey polygon indicates the Eurasian watermilfoil treatment polygon number and area. Within the polygon, the yellow area indicates the area surveyed for the mussel. The red polygon and pin indicate the area in which mussels were found and the number of mussels found.

Figure 5 Polygon 64 Rocky Mountain ridged mussel finds. The find sites are towards the southern end of the western shore of Okanagan Lake (Rotary Beach, Summerland). The white pin and grey polygon indicates the Eurasian watermilfoil treatment polygon number and area. Within the polygon, the yellow area indicates the area surveyed for the mussel. The red polygons and pins indicate the areas in which mussels were found and the number of mussels found.

Figure 6 Polygon 91 Rocky Mountain ridged mussel finds. The find sites are along the central part of the western shore of Okanagan Lake (Casa Loma, West Kelowna). The white pins and grey polygons indicate the Eurasian watermilfoil treatment polygon number and area. Within the polygon, the yellow area indicates the area surveyed for the mussel. The red polygons and pins indicate the areas in which mussels were found and the number of mussels found.

Figure 7 Polygon 109 Rocky Mountain ridged mussel find. The find site is at the eastern end of the Vernon Arm of Okanagan Lake (Kin Beach, Vernon). The white pins and grey polygons indicate the Eurasian watermilfoil treatment polygon numbers and areas. Within the polygons, the yellow area indicates the area surveyed for the mussel. The red polygon and pin indicates the area in which mussels were found and the number of mussels found.

Figure 8 Polygon 117 Rocky Mountain ridged mussel find. The find site is along the southern shore of the Vernon Arm of Okanagan Lake (Okanagan Landing, Vernon). The white pins and grey polygons indicate the Eurasian watermilfoil treatment polygon numbers and areas. Within the polygons, the yellow area indicates the area surveyed for the mussel. The red polygon and pin indicates the area in which mussels were found and the number of mussels found.