Rocky Mountain ridged mussel (*Gonidea angulata*) in the Okanagan Valley, B.C.:

Final report on potential threats from limited fish host availability, introduced fish species, and river restoration, and mitigation of direct damage from the public.

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Photo: Roxanne Snook

OKANAGAN

On behalf of the University of British Columbia – Okanagan,

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Table of Contents

List of Figures

List of Tables

Summary

The Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) is COSEWIC-listed as endangered and SARA-listed as a Species of Concern in Canada, due to its limited distribution and relatively small population size, past and ongoing habitat impacts, and effects of introduced species. It is only found within the Okanagan Valley of British Columbia (B.C.) in Canada, and the province has listed it as imperiled. However, very little is known about the biology of this mussel in general. Even less is known about its current status and the threats to its survival in B.C. From a conservation perspective, priority has been placed on improving the knowledge of the mussel's biology, identifying the threats to the species, and developing appropriate mitigation to reduce those threats. In this project, I investigated three potential threats against RMRM: 1. Host fish availability. 2. Introduced fish species. 3. Restoration of meanders to the Okanagan River. In addition, several collaborators, including myself, tried to reduce a fourth known threat: 4. Direct damage to the mussel by the public.

To determine if limited host fish availability is a threat to RMRM, my research team and I undertook two studies: 1. We undertook a host fish infection experiment, to confirm the host fish use of the mussel in the Okanagan Valley. 2. We undertook fish sampling and surveying, to determine the presence and relative abundance of host fish at the high density mussel beds in the system. Unfortunately, the host fish infection experiment was unsuccessful due to very high temperatures and rapid warming of the waters in the Okanagan Valley during the spring of 2015. However, using data from experiments in the United States of America (U.S.) and host fish field work in the Okanagan, it is possible to determine with high confidence that sculpin (*Cottus* spp.) are the main hosts of RMRM in this system. Further, it is also possible to determine that northern pikeminnow (*Ptychocheilus oregonensis*, Richardson 1836), and leopard (*Rhinichthys falcatus*, Eigenmann and Eigenmann 1893) and longnose dace (*Rhinichthys cataractae*, Valenciennes 1842) are potential hosts for the mussel. Given these findings and the data on fish presence and relative abundance at the high density RMRM beds in the Okanagan, I found that limited availability of host fish is not currently a threat to the mussel in Okanagan Lake. However, the fish data suggest that it is a threat to the mussel in the southern Okanagan Valley.

I investigated whether introduced fish are a threat to RMRM by sampling and surveying to determine the presence and relative abundance of introduced fish at the high density mussel beds in

the system. By combining these data with the data on the host fish, it is possible to evaluate whether introduced fish are likely to have reduced the numbers of host fish and pose a threat to RMRM. In addition, it is possible to evaluate whether introduced molluskivore (animals that eat mollusks) fish are likely to pose a direct threat to the mussel. I suspect that the reduced host fish availability, described above, is due to the introduction of smallmouth bass (*Micropterus dolomieu*, Lacepede 1802) into the southern part of the system. The fact that this fish species has recently been found in Okanagan Lake is of particular concern. If it becomes established in the lake in large numbers, it is likely to reduce the host availability to RMRM in the lake. Other introduced fish are also likely a threat to the mussel as molluskivores, as both common carp (*Cyprinus carpio*, L.) and pumpkinseed sunfish (*Lepomis gibbosus*, L.) are present at many of the high density mussel beds in the Okanagan Valley. Therefore, it is safe to conclude that introduced fish species are a threat to the mussel in this system. In addition, it may be an increasing threat in Okanagan Lake.

In order to evaluate if restoration of meanders to the Okanagan River is a threat to RMRM, my research team and I undertook two studies in natural, restored, and channelized sections of the river: 1. We undertook mussel surveys, to determine which river habitat the mussel is most commonly present in. 2. We undertook fish sampling and surveying, to determine the presence and relative abundance of host fish and detrimental introduced fish in the different habitats. My research team and I found that RMRM almost exclusively were found in the channelized sections of the river, while restored and natural sections of the river have very limited habitat value to the mussel. The impact of the restoration on RMRM through its effect on fish fauna is less clear. We found that the restored areas have higher numbers of one of the potential hosts, northern pikeminnow, and of smallmouth bass and the common carp, which both are very likely to have a negative impact on RMRM. Overall, restoration of meanders to the Okanagan River clearly has had a negative impact on RMRM. However, restoration practices can be improved to increase the availability of habitat to the mussel in restored sections.

To mitigate the direct damage done by users of high density RMRM beds in the Okanagan Valley, Lime Design Inc., in collaboration with the British Columbia Ministry of Environment, the University of British Columbia Okanagan, and the Canadian Department of Fisheries and Oceans, developed and placed RMRM interpretive signage at six public recreational locations where there are high densities of mussels. In addition, the sign was also developed into a poster and delivered to schools, dive shops, marinas, etc., in the Okanagan Valley. To evaluate whether these signs contributed to increased knowledge of RMRM biology and conservation needs, my research team and I conducted interviews among the users of these locations. The results of the interviews show that the awareness of RMRM is very low. However, the placement of interpretive signage has improved the awareness and knowledge about RMRM among users, and is meeting the intended purpose of establishment.

Based on the findings from this project, it is recommended that: 1. One should undertake an investigation to determine if low juvenile RMRM recruitment is a threat to the mussel in the southern part of the system. This would be important in evaluating the health of this part of the population and in determining if host fish availability may be a threat to the mussel. 2. The host fish use should be confirmed via completion of the host infection experiment, which would contribute to increased certainty with respect to the conclusions related to threats from limited host availability and introduced fish species. 3. An invasive fish species assessment, with a special emphasis on smallmouth bass, should be conducted to determine introduced fish current presence in and future likelihood of occupying RMRM habitat in Okanagan Lake. 4. High value habitat in the Okanagan River should be protected from modifications that may impact the necessary habitat features for RMRM. 5. Future restoration of meanders on the Okanagan River should be planned in such a way as to maximize habitat availability to the mussel in the restored sections. 6. Previously restored sections and some of the channelized sections in the Okanagan River should be augmented to increase the available RMRM habitat. 7. Further studies should be undertaken to determine how the RMRM habitat can be maximized during such restorations. 8. Additional interpretive signage should be placed at some of the recently discovered high density RMRM beds in the Okanagan Valley.

Introduction

The Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) is COSEWIC-listed as endangered (COSEWIC 2010) and SARA-listed as a Species of Concern (Fisheries and Oceans Canada 2010) in Canada, due to its limited distribution and numbers, past and ongoing habitat impacts, and effects of introduced species. It is only found within the Okanagan Valley of British Columbia (B.C.) in Canada (Stanton *et al.* 2012), and the province has red-listed it with a S2 status (BC Conservation Data Centre 2015a,b). However, very little is known about the biology of this mussel in general (reviewed in e.g. Jepsen *et al.* 2010, COSEWIC 2003, 2010, Fisheries and Oceans Canada 2010, BC Conservation Data Centre 2015b). Even less is known about its current status and the threats to its survival in B.C. (see discussions in COSEWIC 2003, 2010, Fisheries and Oceans Canada 2010, BC Conservation Data Centre 2015a,b, Stanton *et al.* 2012). From a conservation perspective, priority has been placed on improving knowledge of the mussel's biology, identifying threats to the species, and developing appropriate mitigation to reduce those threats.

In this project, I investigated three potential threats against RMRM: 1. Limited host fish availability. 2. Impact of introduced fish species. 3. Impact of restoration of meanders to the Okanagan River. In addition, several collaborators, including myself, tried to reduce a fourth known threat: 4. Direct damage to the mussel by the public. For further details, see the following sections.

Host fish availability as a potential threat

Introduction

One of the potential threats to Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) is limited fish host availability (COSEWIC 2010, Fisheries and Oceans Canada 2010). If the necessary host fish are not present in the system in sufficient numbers, the mussel will not be able to complete its life cycle (see e.g. Jepsen *et al.* 2010, COSEWIC 2003, 2010, Fisheries and Oceans Canada 2010 for an overview of the mussel lifecycle). Although there are field data that suggest some potential host fish for the mussel (Stanton *et al.* 2012, Mageroy 2015), these findings have not been confirmed through laboratory infection experiments (part of the accepted host fish identification method, see O'Brien et al. 2013). Until the hosts used by RMRM are confirmed, it cannot be determined, with certainty, if limited availability of host fish is a threat to the mussel. In addition to determining the host fish, host fish surveying and sampling is necessary to determine if these fish are present at the mussel beds in sufficient numbers for the mussel to maintain its population numbers. In this study, our aim was to determine the host fish and establish their relative abundance at mussel beds throughout the Okanagan Valley.

Methods

Host fish infection experiment

To determine which fish RMRM can use as hosts, my research team and I undertook an infection experiment. In this experiment I included fish species that field data suggest may function as hosts for the mussel (Stanton *et al.* 2012, Mageroy 2015), fish that are commonly present at the mussel beds in the system, and some of the introduced fish species that are common in the southern part of the Okanagan (*pers. obs.*). The fish species that met the criteria were: Prickly sculpin (*Cottus asper*, Richardson 1836), slimy sculpin (*Cottus cognatus*, Richardson 1836), leopard dace (*Rhinichthys falcatus* Eigenmann and Eigenmann 1893), longnose dace (*Rhinichthys cataractae*, Valenciennes 1842), northern pikeminnow (*Ptychocheilus oregonensis*, Richardson 1836), longnose sucker (*Catostomus catostomus*, Forster 1773), largescale sucker (*Catostomus macrocheilus*, Girard 1856), yellow perch (*Perca flavescens*, Mitchill 1814), smallmouth bass (*Micropterus dolomieu*, Lacepede 1802), and common carp (*Cyprinus carpio*, L. 1758). Fish such as mountain whitefish (*Prosopium williamsoni*, Girard 1856), redside shiner (*Richardsonius balteatus*, Richardson 1836), and lake chub (*Couesius plumbeus*, Agassiz 1850) were excluded from the experiment because field data (Mageroy 2015) showed that these fish do not serve as hosts for the mussel in nature in the Okanagan system.

The fish were collected between the May 21st and 27th, 2015, by my research team and I. They were collected using a beach seine and we only collected juvenile fish, to make housing the fish easier. We collected yellow perch, prickly sculpin, and smallmouth bass from the northern part of Vaseux Lake, in the southern Okanagan Valley. Longnose dace and northern pikeminnow we collected from Gellatly Bay on the central part of Okanagan Lake, which is in the central Okanagan Valley. These locations were chosen as they do not contain RMRM, since previous exposure to mussel larvae can result in immunity to infection among fish (e.g. Coker *et al.* 1921, review in Larsen 1997). The other five species were excluded from the experiment, since we were unable to find juveniles of these species through our sampling effort. Once collected, we transported the fish to our laboratory facilities, using oxygenated holding bags. In the laboratory the fish were maintained in 30 L holding tanks. Each species was held separately and no more than 10 fish were held in each tank. The fish were maintained at 17°C. Each holding tank was part of a recirculating system, in which the water was filtered through a biological filter, chilled, and oxygenated. For further details on the lab setup, see Appendix D.

Starting at the beginning of May, 2015, 20 RMRM were collected from Dog Beach and Kinsmen Park in Summerland, which is on the southern part of Okanagan Lake, on a weekly basis. The mussels were opened slightly, using a snap-ring plier. The gills were inspected to determine if they were swollen and of a lighter color than normal, which indicates that the mussel is gravid (see Spring Rivers 2007 for description of inspecting live mussels for reproductive status). Gravid mussels were transported to the laboratory and samples from their gills were collected. These samples were either collected from spontaneously released conglutinates or by making a small incision in the gills. The developmental stage of the mussel eggs and larvae were determined through visual inspection under a microscope. Maturity and vitality of the larvae were evaluated by visually determining if their valves would open and shut actively.

On June 15th, 2015, mature and live glochidia were collected from 3 gravid RMRM (see O'Brien *et al.* 2013 for methodology). Approximately 5000 glochida were suspended in a 4 L bucket by aerating the water column, with air stones. The fish were transferred to the infection bucket for a 15-minute period, before being transferred back to their holding tanks. 12 prickly sculpin, 6 smallmouth bass, 5 yellow perch, 9 northern pikeminnow, and 15 longnose dace were exposed to the glochidia. Starting on day 5 and every other day thereafter, debris from the bottom of the holding tanks was siphoned into a 70 µm filter sock. The fish had been prevented from accessing this debris by placing a grate on the bottom of each tank. Once the debris had been collected, it was inspected under a microscope to determine if any metamorphosed and live juvenile mussels had dropped from the fish. Whether mussels had successfully metamorphosed, was determined based on whether they were observed to actively move using their foot (see O'Brien *et al.* 2013 for established methodology). The experiment was terminated and all fish were euthanized on July 1st, 2015, as a previous study shows that metamorphosis in RMRM takes 10 to 11 days (O'Brien *et al.* 2013).

Fish surveying and sampling

To determine which fish species are present and their relative abundance at known high density RMRM beds in the Okanagan Valley (Mageroy 2015), my research team and I undertook fish sampling and surveying. Previous data from 2013 exist for Dog Beach and Kinsmen Park in Summerland (summary in Mageroy 2015), which is on the southern part of Okanagan Lake, so these sites were excluded from our sampling and surveys. A site on the northern arm of Okanagan Lake was also excluded due to problems gaining access to the site. However, I included the remaining known high density RMRM beds in the Okanagan Valley: Kin Beach on the Vernon Arm of Okanagan Lake, Three Mile Beach on the southern part of Okanagan Lake, the Vaseux Lake Campsite, and the Fairview Rd. Bridge in downtown Oliver on the Okanagan River. In addition, we also sampled and surveyed for fish and mussel presence to evaluate the effects of restoration projects in the Okanagan River on RMRM (see the 'River restoration as a potential threat' section for further details (pp. 24-33). These surveys revealed further high density mussel beds in the Okanagan River. Therefore, I am including the fish data from these beds in the analysis of fish host availability. These sites are: # 9 Rd. bridge (south of Oliver) and # 18 Rd. bridge (close to Osoyoos Lake). For a complete overview of sites sampled and surveyed for host fish presence and relative abundance, see Figure 1. This figure was produced using ArcMap 10.3.1 (ESRI 2014).

The presence/absence and relative abundance of fish species at RMRM beds in the Okanagan system were evaluated using several methods. All methods described below, follow or are modified from the recommendations made by the British Columbia Resources Information Standards Committee (RISC) (B.C. Ministry of Environment, Lands, and Parks 1997). My research team and I sampled all sites once using 12 minnow traps, with the exception of using 11 traps at the three river sites. The traps were baited with sardines and left overnight (approximately. 16 hrs). In addition, we sampled Kin Beach, Three Mile Beach, and Vaseux Campsite using a gill net. The gill net was set overnight (also approximately 16 hrs) and the net used met the RISC standards (B.C. Ministry of Environment, Lands, and Parks 1997). We were not allowed to set the net in the Okanagan River due to concerns about catching protected salmonids (Tara White, *Pers. com.*). However, we did snorkel survey the river sites. Two or three surveyors snorkeled each site. Two surveyors were only used for channelized sections of the river, as in our experience there is minimal difference in the number of fish observed between two and three surveyors on these sections. This is due to almost all fish being observed along the banks of the channel, while only a minimal number of fish are observed in the central part of the channel (*Unpubl. data*). If three surveyors were present, the surveyors drifted down the river channel along each bank and in the center. If only two surveyors were present, the center of the channel was abandoned. The other sites were not snorkel surveyed as this method is not effective in lakes (B.C. Ministry of Environment, Lands, and Parks 1997). The only site that we sampled using a beach seine was the Vaseux Campsite. Twelve seine sets were made at this site. The other sites were not beach seined, as the sites were not suitable for this sampling method. We completed the sampling and surveying between June 9th and July 8th, 2015, which is normally during the middle of the RMRM reproductive period (see Stanton *et al.* 2012, Mageroy 2015). However, this year these dates fell immediately following the reproductive period due to warmer than normal weather (*Pers. obs.*).

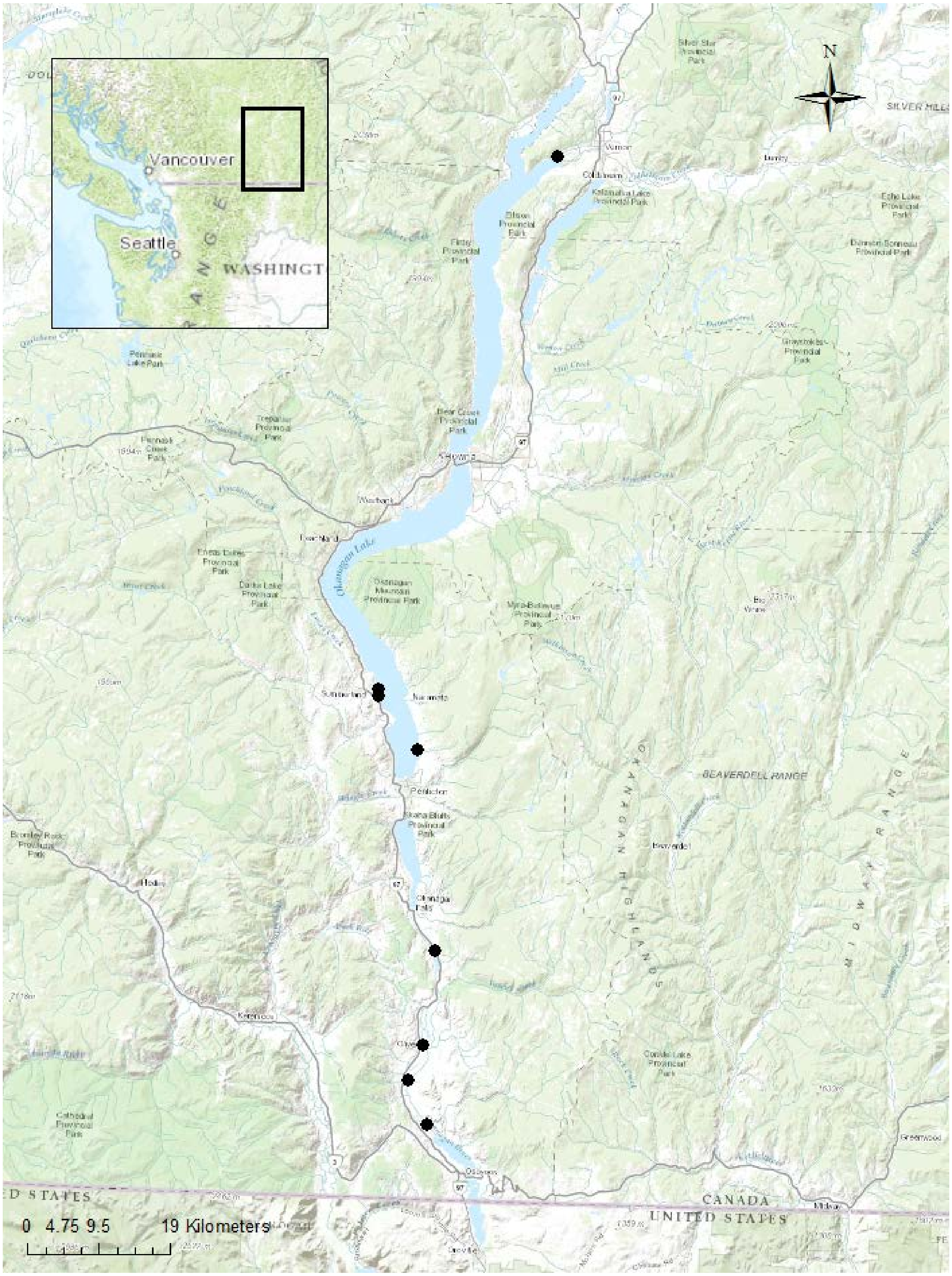

Figure 1 High density Rocky Mountain ridged mussel sites. ● indicates known high density RMRM beds in the Okanagan Valley that were surveyed for fish presence and relative abundance. (Source: ESRI.)

Results

Host fish infection experiment

No metamorphosed juvenile RMRM were collected during the experiment.

Fish surveying and sampling

Due to the unsuccessful outcome of the host fish infection experiment, I cannot report on the presence and relative abundance of confirmed host species for RMRM. Therefore, the data shown in Table 1 reports on the presence and relative abundance of probable and potential host fish at the high density RMRM beds in the Okanagan Valley. These fish include prickly sculpin, which is very likely the main host for the mussel in the Okanagan, given previous field findings from the Okanagan (Stanton *et al.* 2012, Mageroy 2015) and results on the mussel's host use in the U.S. (Spring Rivers 2007, O'Brien *et al.* 2013, Alexa Maine *Pers. com.*). In addition, the field findings show that northern pikeminnow (Stanton *et al.* 2012), and longnose and leopard dace (Mageroy 2015) may also serve as hosts for RMRM. For full details on all fish species caught, see Appendix A.

Discussion

Due to the very early summer and unusually rapid warming of the waters in the Okanagan system during 2015, the host fish infection experiment was not successful and, therefore, the host fish use of RMRM in the Okanagan Valley could not be confirmed. Fish cannot be successfully collected in the system until the water temperatures reaches about 12°C, due to low activity among the fish (Jerry Mitchell, *Pers. com.*). However, due to air temperatures reaching summer temperatures three to four weeks earlier than normal, water temperatures went from 12°C to over 20°C in less than two weeks. Unfortunately, this rapid heating of the water resulted in RMRM spawning about a month earlier than

Table 1 Presence and relative abundance of potential host fish. The table shows the results of our fish sampling and surveying with respect to host fish availability. It does not show all fish species sampled and surveyed, but only those species that are potential hosts for RMRM based on previous data (Spring Rivers 2007, Stanton *et al.* 2012, O'Brien *et al.* 2013, Mageroy 2015, Alexa Maine *Pers. com.*). The data for Dog Beach and Kinsmen Park in Summerland are from 2013 (work summarized in Mageroy (2015), although the actual numbers are based on data not shown in that report. 'None' indicates that none of the potential host fish were found at the site. 'NA' indicates that the method was not used at the site. * indicates that the number of fish has been adjusted to account for sampling effort in the form of days sampled and traps set. ** indicates that the number of fish has been adjusted to account for sampling effort in the form of days sampled. The adjustments were made to make the fish numbers comparable among sites.

Site	Minnow Traps	Gill Net	Beach Seine	Snorkel Survey
Kin Beach, Vernon Arm, Okanagan Lake	6 prickly sculpin 11 northern pikeminnow	1 prickly sculpin 34 northern pikeminnow	NA	NA
Dog Beach, Summerland, Okanagan Lake	8 prickly sculpin*	None	15 prickly sculpin** 2 longnose dace**	NA
Kinsmen Park, Summerland, Okanagan Lake	4 prickly sculpin*	15 northern pikeminnow	31 prickly sculpin** 4 longnose dace**	NA
Three Mile Beach, Penticton, Okanagan Lake	5 prickly sculpin	2 prickly sculpin 27 northern pikeminnow	NA	NA
Vaseux Lake Campsite, Oliver, Vaseux Lake	None	4 northern pikeminnow	1 prickly sculpin	NA
Fairview Rd. Bridge, Oliver, Okanagan River	None	NA	NA	2 northern pikeminnow
# 9 Rd. bridge, Oliver, Okanagan River	None	NA	NA	None
# 18 Rd. bridge, Oliver, Okanagan River	None	NA	NA	None

normal (*Pers. obs.*). Due to the short (two week) time period, between fish becoming active and the spawning of the mussels, my research team and I were not able to collect the fish necessary for the experiment before the main spawning period of the mussels was over. Therefore, we used glochidia (mussel larvae) collected at the end of RMRM spawning period for the experiment. Visual inspection of the glochidia showed that they were not of high quality. However, I decided to complete the experiment as the additional work load was small. Unfortunately, the poor quality of the glochidia evidently resulted in no successful metamorphosis into juvenile mussels on the fish.

Due to the unsuccessful outcome of the infection experiment, it is difficult to determine, with certainty, whether host availability is a threat to RMRM in the Okanagan Valley. However, as discussed in the results section, it is possible to use the results of previous host studies to determine the likely hosts of the mussel in this system. Laboratory studies from the U.S. (Spring Rivers 2007, O'Brien *et al.* 2013, Alexa Maine *Pers. com.*) and field data from the Okanagan (Stanton *et al.* 2012, Mageroy 2015) strongly suggest that sculpin (*Cottus* spp.) serve as the primary host in the Okanagan. In addition, the field data also suggest that northern pikeminnow, and longnose and leopard dace may serve as secondary hosts for RMRM in the Okanagan Valley (Stanton *et al.* 2012, Mageroy 2015). However, the data from the U.S. suggest that pikeminnows (*Ptychocheilus* spp.) do not serve as hosts (Spring Rivers 2007, O'Brien *et al.* 2013). Further, longnose dace was shown to not serve as a host for the mussel in one of the studies (O'Brien *et al.* 2013). Therefore, it is safe to assume that sculpin are the main host for the species in the Okanagan Valley, while it is more uncertain whether northern pikeminnow, and longnose and leopard dace serve as secondary hosts for the mussel. Given these findings it is possible to use my data on fish presence and relative abundance, at the high density RMRM beds in the Okanagan Valley, to discuss whether host availability is a likely threat to the mussel in this system.

Prickly sculpin was present at five of the eight sites my research team and I surveyed and sampled (see Table 1). The data from Dog Beach and Kinsmen Park show that the relatively low catches of prickly sculpin in the minnow traps correspond to quite high catches with a beach seine. Therefore, it is safe to assume that this species of sculpin is also common at Kin Beach and Three Mile Beach. Visual observation during snorkel surveying for mussels is consistent with these findings (*Pers. obs.*). Only one sculpin was collected through beach seining at Vaseux Lake Campsite, suggesting that it is quite uncommon at this site. No sculpin were observed or collected for any of the sites on the Okanagan River. However, this may partially be explained by sampling method limitations. We were unable to beach seine in the river, due to the flow of the water. Since seining seems to be the most efficient way of collecting sculpin, this may have limited our ability to catch sculpin. In addition, I do know that sculpin are present in the river, as two specimens were found at other sites (see Table 8 in Appendix A). Even so, I would expect to catch some sculpin in minnow traps, if they are common at the site. Overall, these findings show that sculpin are common at high density mussel beds in Okanagan Lake, but suggest that they are less common in the southern Okanagan Valley.

Northern pikeminnow and/or longnose dace were present at six of the eight sites (see Table 1). Therefore, these two fish species may provide additional hosts to RMRM. This is especially important at the sites with low no or low numbers of sculpin. Northern pikeminnow was found in low numbers at two of these sites and it was not found at the two other low sculpin sites. It was only present in high numbers at three of the sites, which also had high sculpin numbers. Longnose dace was only found at two sites, which may be explained by our inability to catch or observe it through any other method than beach seining. Even so, this species was only found in low numbers at the two sites where it was present. Overall, it seems these two fish species could have the potential to provide additional hosts for RMRM. Interestingly, they are more common at the high density mussel beds in Okanagan Lake than in the southern Okanagan Valley, similarly to sculpin.

Host fish seem to be readily available to RMRM in Okanagan Lake, but not in the southern Okanagan Valley. This implies that limited host fish availability may be a threat to the mussel in the southern part of the system. However, surveys from 2013 show that juvenile mussels are being recruited into the population at both the Vaseux Lake Campsite and Fairview Rd. Bridge, although the surveys did not reveal whether the recruitment was sufficient to maintain RMRM numbers (Mageroy 2015). These findings suggest that some host fish are available to the mussels, even in the southern Okanagan Valley. This may be explained by sculpin being present in the system at higher numbers than what my research team and I found, which may be due to the limitations in collection methods described above. In addition, it may be due to introduced smallmouth bass (For further details on the impact of smallmouth bass, see the 'Introduced fish as a potential threat' section (pp. 18-23).) altering the behavior of the sculpin and making them less easy to collect in the southern part of the system. Alternatively, an unknown fish species may serve as hosts for the mussel.

In conclusion, the limited availability of host fish is not currently a threat to RMRM in Okanagan Lake, but the fish data suggest that it may be a threat to the mussel in the southern Okanagan Valley. Further studies will be needed to confirm this: 1. Investigations on juvenile recruitment by RMRM at the mussel beds in the southern Okanagan would determine if lack of recruitment is a threat to the mussel in this part of the system. If recruitment is sufficient to maintain mussel numbers, one could infer that host fish availability is not a threat (see discussion in Mageroy 2015). If recruitment is insufficient to maintain mussel numbers, one knows that host fish availability may be a threat to the mussel. 2.

Successful completion of the infection experiment would provide more certainty with regards to host fish numbers at the mussel beds. 3. Compiling additional fish data would make the findings more resilient. Our fish surveys and sampling were limited by financial constraints and the work load required to complete the infection experiment.

Introduced fish as a potential threat

Introduction

Another potential threat to Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) is introduced fish species (COSEWIC 2010, Fisheries and Oceans Canada 2010), as many species are quite common in the Okanagan Valley. This is especially the case in the southern Okanagan (Jerry Mitchell, *Pers. com.*). Such fish may affect the mussel negatively in two ways: 1. They may predate on or outcompete native fish, thereby reducing the available number of hosts to the mussel (COSEWIC 2010). This would only be a threat if the introduced fish cannot serve as hosts for the mussel. Therefore, it is necessary to test if the introduced fish species present in the Okanagan system can serve as host fish for the mussel. If these introduced fish cannot serve as hosts for the mussel, fish surveys and sampling are necessary to determine if these introduced fish have displaced the native host fish from the mussel beds and pose a threat to host availability for the mussel. 2. If the introduced fish are molluskivores (animal that eats mollusks), they may directly predate on the mussels (see discussion in COSEWIC 2010).

Determining if introduced fish species are a threat to RMRM is especially important since modifications of one dam to allow for fish passage upstream has taken place on the Okanagan River (Canadian Okanagan Basin Technical Work Group; http://www.obtwg.ca), and further such modifications may be under consideration (Lora Nield *Pers. com.*). Such alterations may allow introduced fish species, which are only present south of Okanagan Lake, to colonize new sections of the system. Therefore, it increases the importance of completing fish surveys and sampling, at high density RMRM beds in the Okanagan Valley, to determine if introduced fish pose a threat to the mussel by displacing host fish and/or by predating directly on the mussel. In this study, we undertook such fish surveys and sampling.

Methods

The methods employed for sampling and surveying introduced fish species are identical to the methods used for the host fish availability surveys. Therefore, see the 'Fish surveying and sampling' methodology in the 'Host fish availability as a potential threat' section (pp. 10-11).

Results

Table 2 reports the presence and relative abundance of introduced fish species at high density RMRM sites in the Okanagan Valley. The fish species found include pumpkinseed sunfish (*Lepomis gibbosus* L. 1758), yellow perch (*Perca flavescens*, Mitchill 1814), smallmouth bass (*Micropterus dolomieu*, Lacepede 1802), brown bullhead (*Ameiurus nebulosus*, Lesueur 1819), common carp (*Cyprinus carpio*, L. 1758), largemouth bass (*Micropterus salmoides*, Lacepede 1802), and black crappie (*Pomoxis nigromaculatus*, Lesueur 1829). For full details on all fish species caught, see Appendix A.

Discussion

Overall, the results demonstrate that introduced fish species are quite common in the Okanagan Valley (see Table 2). This seems to especially be the case in the southern part of the system, where smallmouth bass was common at all sites and common carp was common at three of the four sites. The presence of these two species in large numbers throughout the southern part of the system, was confirmed by additional fish surveys on the Okanagan River (see Appendix A). In addition, other introduced fish species were present at some of the sites in low numbers. Introduced fish were less common in Okanagan Lake, as they only were present at two of the four sites. At these sites, yellow perch was the dominant introduced fish species.

One potential threat from introduced fish to RMRM is that they may predate on or outcompete native fish, thereby reducing the available number of hosts to the mussel (COSEWIC 2010). From this

Table 2 Presence and relative abundance of introduced fish species. The table shows the result of our fish sampling and surveying with respect to introduced fish species. Note that the data for Dog Beach and Kinsmen Park in Summerland are from 2013 and come from Mageroy (2015), although the actual numbers are based on data not shown in that report. None indicates that no introduced fish were found at the site. 'NA' indicates that the method was not used at the site.

Site	Minnow Traps	Gill Net	Beach Seine	Snorkel Survey
Kin Beach, Vernon Arm, Okanagan Lake	1 pumpkinseed sunfish	31 yellow perch 1 common carp	NA	NA
Dog Beach, Summerland, Okanagan Lake	None	None	None	NA
Kinsmen Park, Summerland, Okanagan Lake	None	6 yellow perch 2 common carp	None	NA
Three Mile Beach, Penticton, Okanagan Lake	None	None	NA	NA
Vaseux Lake Campsite, Oliver, Vaseux Lake	1 yellow perch	20 smallmouth bass 6 pumpkinseed sunfish 6 yellow perch 5 brown bullheads 2 common carp 2 largemouth bass 1 black crappie	17 smallmouth bass 2 pumpkinseed sunfish	NA
Fairview Rd. Bridge, Oliver, Okanagan River	2 pumpkinseed sunfish	NA	NA	50 smallmouth bass 19 common carp 3 pumpkinseed sunfish
# 9 Rd. bridge, Oliver, Okanagan River	3 smallmouth bass 2 brown bullheads	NA	NA	16 smallmouth bass 11 common carp
# 18 Rd. bridge, Oliver, Okanagan River	3 smallmouth bass	NA	NA	7 smallmouth bass 3 common carp

perspective, smallmouth bass is of special interest since it is a very efficient piscivore (animal that eats fish) in rivers, streams, and in the littoral zone of lakes. In addition to having the potential to predate on native species, it can also outcompete native species (see overview of smallmouth bass biology in Brown *et al.* 2009a). The fact that it was found in high numbers at all the mussel beds in the southern part of the Okanagan Valley (see Table 2), makes it very likely to affect the availability of native host fish to RMRM. Therefore, it is interesting to note that sculpin (*Cottus* spp.) numbers are low in parts of the system that contain smallmouth bass, while they are high in parts of the system that does not contain smallmouth bass (For sculpin data, see the results in the 'host fish availability as a potential threat' section (p. 13).). A similar, although lesser, trend appears to be the case for northern pikeminnow (*Ptychocheilus oregonensis*, Richardson 1836) (For pikeminnow data, see the results in the 'host fish availability as a potential threat' section (p. 13).), which has been shown to decline in numbers when smallmouth bass is introduced to a system (Brown *et al.* 2009a). Therefore, it is very likely that the introduction of smallmouth bass has contributed to a decline in native host fish numbers in the southern Okanagan Valley.

Yellow perch is another piscivore, which inhabits the littoral zone and is known to outcompete native fish (see overview of yellow perch biology in Brown *et al.* 2009b). Unlike smallmouth bass it is found throughout the Okanagan Valley, but my data show that it is most commonly found in lakes and slower parts of the Okanagan River (see Table 2 and Appendix A). It was found in high numbers at two of five high density RMRM beds in Okanagan Lake and could affect the native host fish availability to the mussel. However, both prickly sculpin (*Cottus asper*, Richardson 1836) and northern pikeminnow are common at these two sites. Therefore, it appears likely that the introduction of yellow perch does not pose a threat to the availability of native host fish to the mussel.

The common carp is not a piscivore, but it can predate on fish eggs and alter habitat in a way that can displace native fish (see overview of common carp biology in Nico *et al.* 2015). It is present throughout the Okanagan Valley and was found at six of the eight high density RMRM beds (see Table 2). In addition, my research team and I have also seen them at the two other beds while doing mussel surveys (*Pers. obs.*). Although it only was found in high numbers at a couple of the sites, these are large fish with the ability to greatly alter the habitat through their feeding (Nico *et al.* 2015). Their potential impact could, therefore, be greater than what their numbers indicate. However, host fish were present in large numbers in Okanagan Lake (For native host fish data, see the results in the 'host fish availability as a potential threat' section (p. 13).), despite the presence of the common carp. Therefore, it seems likely that the introduction of the common carp does not pose a threat to the availability of native host fish to the mussel.

Despite smallmouth bass seeming to have reduced the availability of native fish hosts to RMRM in the southern Okanagan Valley, this does not necessarily reduce overall host availability if introduced fish species could serve as hosts for the mussel. However, smallmouth bass has been shown to not serve as a host for RMRM in Oregon (O'Brien *et al.* 2013). In addition, both the study from Oregon and a study from California show that the mussel only utilizes a very limited number of native host species (Spring Rivers 2007, O'Brien *et al.* 2013). Therefore, it is unlikely that RMRM in the Okanagan Valley can utilize any of the introduced fish species as hosts. Overall, it appears that introduced fish, and especially smallmouth bass, are a threat to the mussel by reducing the availability of host fish to the mussel.

Another potential threat from introduced fish to RMRM is that they may predate on the mussel (see discussion in COSEWIC 2010). The pumpkinseed sunfish is a specialized molluskivore (animal that eats mollusks) that can consume large quantities of smaller mollusks (see review in Strayer 1999). Due to its relatively small size it can probably not predate on adult RMRM, but it is likely that it could consume juvenile mussels. Whether it is able to do so despite the fact that the vast majority of juvenile mussels are buried (Mageroy 2015) is an open question. The pumpkinseed sunfish was found at three of the eight high density mussel beds in the Okanagan Valley (see Table 2). However, the numbers were quite low, so the level of predation on the mussel should also be quite low. The common carp is a generalist, which can consume mollusks as a part of its diet (see review in Garcia-Berthou 2001). Due to its large size, it is likely able to consume adult RMRM. In addition, it disturbs the substrate when feeding (Nick *et al.* 2015) and is likely to consume buried mussels, including juveniles. As described above, they are present at all the mussel beds in the system. Therefore, they are likely to exert some predation pressure on the mussel and this level of predation may be higher in the Okanagan River, as the common carp appears to be more common there than in the lakes. Overall, it seems that introduced fish, such as pumpkinseed sunfish and common carp, may be a threat to RMRM through direct predation.

In conclusion, introduced fish seem to pose a threat to RMRM in the Okanagan Valley: 1. These fish pose a threat through reducing the availability of host fish to the mussel. However, to confirm this finding it will be necessary to successfully complete the host infection experiment. Including the more common introduced fish species in this experiment would determine whether introduced fish serve as hosts for RMRM, despite this being an unlikely scenario. 2: The introduced fish also pose a threat to the mussel by predating on it. Keeping these threats, from introduced host fish in mind, is very important with respect to the conservation of the mussel, as modifications of dams to allow for fish passage upstream has taken place on the Okanagan River (Canadian Okanagan Basin Technical Work Group; http://www.obtwg.ca), and further such modifications may be under consideration (Lora Nield *Pers. com.*). Such alterations may allow introduced fish species that are only present south of Okanagan Lake (e.g. black crappie and largemouth bass) to colonize new sections of the system. However, for smallmouth bass this point may already be inconsequential, as this species has recently been found in Okanagan Lake (Jerry Mitchell, *Pers. com.*). This is of particular concern, as its establishment in the lake in large numbers is likely to reduce the host availability to RMRM in the lake. Further action to aid in the recovery of RMRM could involve trying to eradicate or reduce the numbers of introduced fish.

River restoration as a potential threat

Introduction

A third potential threat to the Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) is the historic channelization and damming of the Okanagan River (see COSEWIC 2010, Fisheries and Oceans Canada 2010). There are alterations currently underway to mitigate some of these historical alterations. Between 2009 and 2013 old meanders were reconnected to the river (Canadian Okanagan Basin Technical Work Group; http://www.obtwg.ca), and further such restoration work is planned/underway (Lynnea Wiens *Pers. com.*). Surprisingly, river surveys in 2013 gave the impression that there were substantially more mussels in the channelized sections of the river than in the natural and restored sections of the river (*Unpubl. data*). More thorough surveys would be necessary to confirm or reject this impression, and determine if the channelized or the natural sections of the river provide better habitat for the mussel. Further, there is no knowledge of how this alteration may affect the habitat availability for RMRM host fish and introduced fish, including molluskivores (animals that eat mollusks). Therefore, fish surveys and sampling are necessary to determine if restoring meanders to the river alter the fish community in a way that affects the mussel. In this study, we undertook both mussel and fish surveys to evaluate how river restoration affects RMRM.

Methods

To determine how Okanagan River meander restoration affects/will affect RMRM habitat availability, my research team and I undertook both mussel surveys, and fish surveys and sampling. The surveys and sampling were completed within the natural, restored, and channelized sections of the river. All sites were located between Vaseux Lake and Osoyoos Lake, since this is the section of the river that has been restored and to minimize the impact of other factors (not related to river type) on my results. These sites include McIntyre Dam, the Gallagher Lake Development, the Highway Bridge north of Oliver (all on the natural or semi-natural section of the river), the Spawning Channel, the Northern

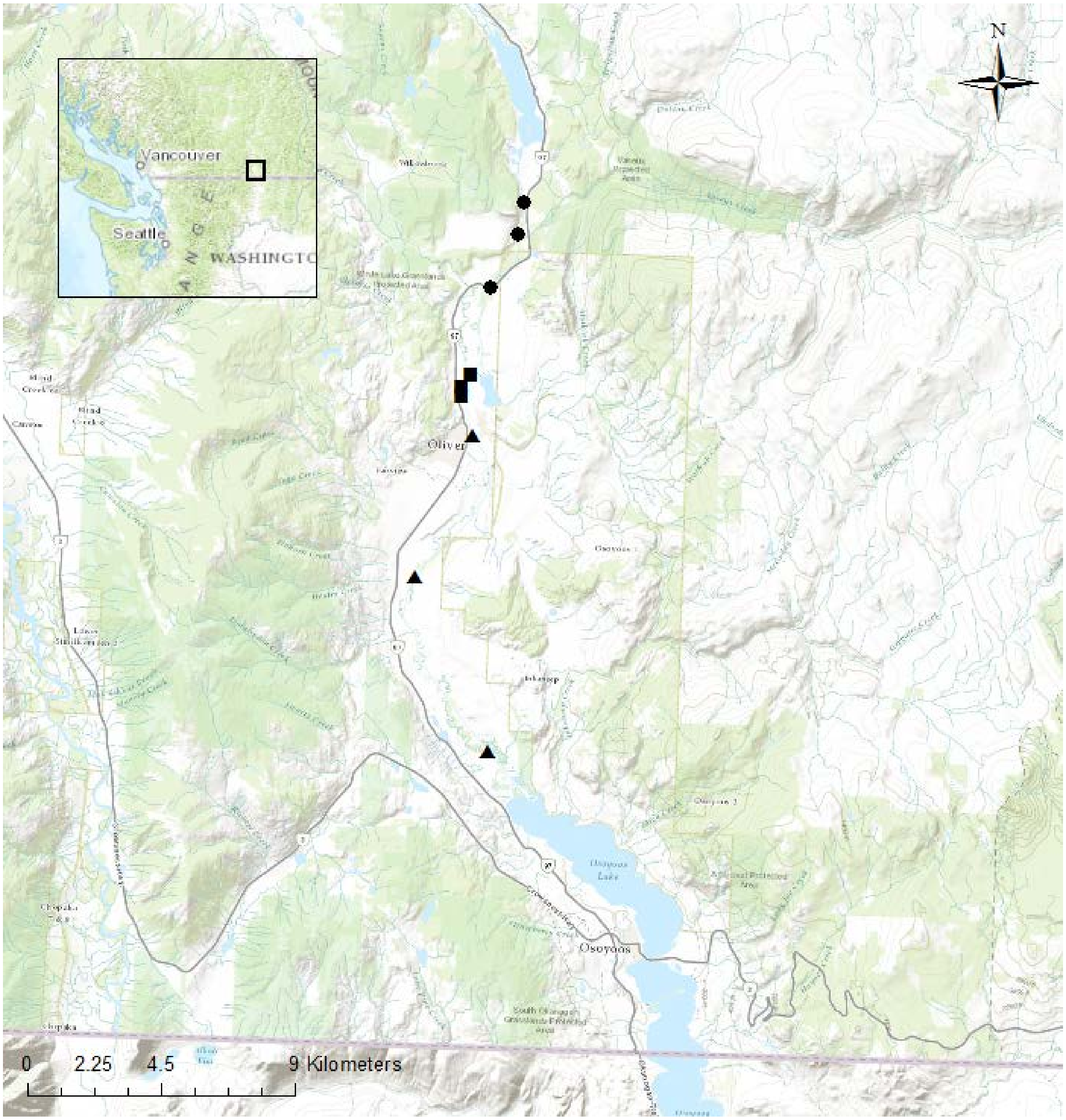

Figure 2 River restoration evaluation sites. Sampling and surveying was completed both for mussels and for fish at each site. ● indicates sites on the natural section of the river. ■ indicates sites on the channelized section of the river. ▲ indicates restored sites. (Source: ESRI.)

Restored Meander, the Southern Restored Meander (all restored sections of the river), Fairview Rd. Bridge, # 9 Rd. Bridge, and # 18 Rd. Bridge (all on the channelized section of the river). For a complete overview of sites sampled and surveyed to determine the impact of river meander restoration on

RMRM, see Figure 2. This figure was produced using ArcMap 10.3.1 (ESRI 2014). All methods described below, follow or are modified from the recommendations made by the British Columbia Resources Information Standards Committee (B.C. Ministry of Environment, Lands, and Parks 1997).

Mussel surveys

With respect to mussels, the three channelized sites were not surveyed since adequate survey data for these sites was available from 2013 (*Unpubl. data*). However, all the remaining sites were surveyed on July 2nd or 3rd, 2015. All sites, both those surveyed in 2013 and 2015, were snorkeled by two or three surveyors. Two surveyors were only used for channelized sections of the river, as in our experience there is minimal difference in the number of mussels observed between two and three surveyors on these sections. This is due to almost all mussels being observed along the banks of the channel, while only a minimal number of mussels are observed in the central part of the channel (*Pers. obs.*). If three surveyors were present, the surveyors drifted down the river channel along each bank and in the center. If only two surveyors were present, the center of the channel was abandoned.

Fish surveying and sampling

With respect to the fish, all sites were surveyed and sampled between July 2nd and 8th, 2015. All sites were both sampled with minnow traps and surveyed by snorkelers. Eleven traps were used at each site. Otherwise, the minnow trapping and snorkel survey methods were the same as those described in the 'Host fish availability as a potential threat' section (pp. 10-11).

Table 3 Rocky Mountain ridged mussel relative abundance at river restoration evaluation sites. Note that the data for the three channelized sites are from surveys completed in 2013 (*Unpubl. data*).

River Type	Site	RMRM	Survey Length (km)	RMRM/km
Natural	McIntyre Dam	0	1.26	0
	Gallagher Lake Development	0	0.58	0
	Highway Bridge	1	2.00	0.5
Restored	Spawning Channel	0	0.23	0
	Northern Restored Meander	0	0.19	0
	Southern Restored Meander	4	0.18	22
Channelized	Fairview Rd. Bridge	369	0.58	636
	# 9 Rd. Bridge	252	2.22	114
	# 18 Rd. Bridge	46	0.49	94

Results

Mussel surveys

Table 3 reports on the relative abundance of RMRM in natural, restored, and channelized sections of the Okanagan River. The mean numbers of RMRM per km were 0.3, 6.7, and 202.7 for the natural, restored, and channelized sections, respectively. As a part of the overall survey effort for the mussel, additional sites on the river were also surveyed. For the survey results for these sites, see Appendix B.

Fish surveying and sampling

Table 4 reports on the presence and relative abundance of potential host fish and introduced fish species in natural, restored, and channelized sections of the Okanagan River. Table 5 reports on the mean number of potential host fish and introduced fish species per km at river restoration evaluation

Table 4 Presence and relative abundance of potential host fish and introduced fish species at river restoration evaluation sites. The table shows the result of our fish sampling and surveying with respect to host fish availability and introduced fish species in natural, restored, and channelized sections of the Okanagan River. It does not show all fish species sampled and surveyed, but only those species that are potential hosts for RMRM, based on previous data (Spring Rivers 2007, Stanton *et al.* 2012, O'Brien *et al.* 2013, Mageroy 2015, Alexa Maine *Pers. com.*), or introduced fish species. 'None' indicates that none of the potential host fish were found at the site.

River Type	Site	Potential Host Fish		Introduced Fish	
		Minnow Traps	Snorkel Survey	Minnow Traps	Snorkel Survey
Natural	McIntyre Dam	None	None	1 smallmouth bass	15 smallmouth bass
	Gallagher Lake Development	None	None	None	4 smallmouth bass
	Highway Bridge	1 prickly sculpin	4 northern pikeminnow	2 smallmouth bass	44 smallmouth bass 3 common carp
Restored	Spawning Channel	1 northern pikeminnow	1 northern pikeminnow	1 smallmouth bass 1 pumpkinseed sunfish 1 yellow perch	4 smallmouth bass
	Northern Restored Meander	None	17 northern pikeminnow	2 smallmouth bass 1 pumpkinseed sunfish	32 smallmouth bass 4 common carp
	Southern Restored Meander	None	8 northern pikeminnow	1 smallmouth bass	51 common carp 16 smallmouth bass
Channelized	Fairview Rd. Bridge	None	2 northern pikeminnow	2 pumpkinseed sunfish	50 smallmouth bass 18 common carp 3 pumpkinseed sunfish
	# 9 Rd. Bridge	None	None	3 smallmouth bass 2 brown bullheads	16 smallmouth bass 11 common carp
	# 18 Rd. Bridge	None	None	3 smallmouth bass	7 smallmouth bass 3 common carp

sites. As a part of the overall survey effort for fish, additional sites on the river were also surveyed. For the survey results for these sites and all fish species caught, see Appendix A.

Discussion

Our RMRM surveys show that this mussel is by far most commonly present in the channelized sections of the Okanagan River (see Table 3). They also show that it is almost non-existent in the natural

Table 5 Mean number of fish per km at river restoration evaluation sites. The table shows the mean number of potential host fish and introduced fish species per km at river restoration sites. It does not show all fish species sampled and surveyed, but only those species that are potential hosts for RMRM (only northern pikeminnow was observed), based on previous data (Spring Rivers 2007, Stanton *et al.* 2012, O'Brien *et al.* 2013, Mageroy 2015, Alexa Maine *Pers. com.*), or introduced fish species. These data are from snorkel surveys, as snorkel surveys are the only surveys that have survey lengths associated with them.

Fish Species	River Type	Fish Number	Survey Length (km)	Fish/km
Northern pikeminnow	Natural	4	3.84	1
	Restored	26	0.60	43.3
	Channelized	2	1.49	1.3
Smallmouth bass	Natural	63	3.84	16.4
	Restored	52	0.60	86.7
	Channelized	73	1.49	49
Common carp	Natural	3	3.84	0.8
	Restored	55	0.60	91.8
	Channelized	32	1.49	21.5
Pumpkinseed sunfish	Natural	0	3.84	0
	Restored	0	0.60	0
	Channelized	2	1.49	1.3

sections of the river, but that there has been some (re-)colonization of one of the restored sections of the river. These findings are confirmed by the mean numbers of RMRM per km found for the three river types at the river restoration evaluation sites, which were 0.3, 6.7, and 202.7 for the natural, restored, and channelized sections, respectively. Similar numbers were also found when comparing RMRM numbers per km for all sections of the Okanagan River between Vaseux and Osoyoos Lakes (0.3, 6.7, and 111.8 for the natural, restored, and channelized sections, respectively. See Appendix B).

Several studies have shown that habitat availability is a major determinant of RMRM presence and density. In a habitat model for Okanagan Lake, Snook (2015) showed that high embeddedness favored the mussel. This variable is a measure of how high a percentage of fine substrate (e.g. sand and silt) surrounds coarser substrate (e.g. boulders and cobble) (Sylte & Fischenich 2002). However, riverine studies from the US have shown that silt has a negative impact on RMRM (Hegeman 2012, Davis *et al.* 2013), while sand has a positive impact on the mussel (Vannote & Minshall 1982, Davis *et al.* 2013). The latter is corroborated by the findings from Okanagan Lake (Snook 2015). Some of the riverine studies also showed the importance of the stability of the substrate for the presence of RMRM (Hegeman 2012, Davis *et al.* 2013). In the channelized sections of the Okanagan River, habitat surveys show that the mussels are associated with high embeddedness and sand, banks stabilized by cobbles, and boulders (Snook *In prep.*). Therefore, one should expect to find the mussel in areas within the river that have stable substrates with high embeddedness and sand.

Although my research team and I did not measure habitat variables in the Okanagan River, there were distinct differences in the substrate characteristics between the river types. In the natural sections, there were lots of boulders and cobbles. However, there was not a lot of sand and the embeddedness was low. In addition, where sand was present the substrate was highly unstable. The restored sections of the river contained hardly any cobbles and only a few boulders, but it did contain quite a bit of sand. However, the substrate was mostly unstable. In the channelized sections, we found RMRM in two very defined microhabitats. The mussels were mostly found in close proximity to where the bank hit the channel bottom. The banks are very defined at these sites and not too steep. This microhabitat had substrate which was quite stable, and was characterized by cobbles embedded in sand. Alternatively, the mussels were found below weirs. At these locations, the mussels were typically found in sand under boulders, which likely stabilize the substrate (*Pers. obs.*). These findings correspond well to the riverine habitat described by Snook (*In prep.*) for the Okanagan River. Therefore, it seems that the characteristic we found for RMRM habitat in the river are similar to those described in previous studies on riverine habitat for the mussel.

This difference in habitat may be explained by several factors. The remaining natural sections of the Okanagan River have mostly a steeper slope than the restored and channelized sections (*Pers. obs*). The difference in slope could explain the difference in available stable substrate with sand. However, the southernmost natural sections of the river have a similar slope to the restored and channelized sections (*Pers. obs.*), but contain a minimal number of RMRM. The substrate instability in the restored sections of the river could be explained by the fairly recent restoration work (2009-2013) (Canadian Okanagan Basin Technical Work Group; http://www.obtwg.ca), and one would expect the substrate to become more stable over time, especially as vegetation increases in the restored sections. However, the restored sections lack the defined banks, with the stable substrate of cobbles and sand, which characterize the RMRM microhabitat in the channelized sections. It is interesting to note that this microhabitat is also absent from the Penticton Channel and channelized sections of the Okanagan River above Vaseux Lake (*Pers. obs.*), and that these sections have minimal numbers of the mussel (See Table 13 in Appendix B). Based on these observations it is evident that the channelized sections of the Okanagan River, below Vaseux Lake, provide the best habitat for RMRM.

Based on the findings discussed above, it seems that further restoration of meanders in this part of the river would have a negative impact on habitat availability to RMRM. However, that would not necessarily have to be the case. The completed restorations do not have the habitat characteristics that favor the mussel. Future restoration practices could be improved to maximize the available habitat to the mussel. Such restorations should aim to create well defined and not too steep banks, with substrate stabilized by cobbles and boulders. In addition, boulders should be added to the channel bottom to create additional areas with stable substrate. Such actions could also be taken to increase the availability of RMRM habitat in the previously restored sections, the Penticton channel and channelized sections of the Okanagan River above Vaseux Lake. Even in the high RMRM density areas of the channelized river below Vaseux Lake, adding boulders to the channel bottom would likely increase the available mussel habitat. Further studies would be needed to determine how restoration of meanders and augmentation of channelized sections should be completed to improve habitat availability. However, what we do know about the habitat characteristics of high RMRM density sections of the Okanagan River can be used to inform any future restorations.

Our fish sampling and surveys give a less clear picture of the impact of restoration of meanders, to the Okanagan River, on the fish fauna. With respect to potential host fish, the catch of prickly sculpin (*Cottus asper*, Richardson 1836) was so low in all river types that there is no point in discussing it further (see Table 4 and Appendix A). Northern pikeminnow (*Ptychocheilus oregonensis*, Richardson 1836) was more common in the restored areas than in either of the other river types, as shown by both minnow trapping and snorkel surveying at the river restoration evaluation sites (Table 4 and Appendix A). These findings are confirmed by the mean number of this fish per km found for the three river types at the river restoration evaluation sites, which was 1, 43.3, and 1.3 for the natural, restored, and channelized sections, respectively (Table 5). Similar numbers were also found when comparing pikeminnow numbers per km for all sections of the Okanagan River that my research team and I snorkel-surveyed for fish (3.5, 43.3, and 1.3 for the natural, restored, and channelized sections, respectively. See Appendix A).

With respect to introduced fish, the results were more apparent. Both smallmouth bass (*Micropterus dolomieu*, Lacepede 1802) and common carp (*Cyprinus carpio*, L. 1758) were most common in the restored sections (see Tables 4 and 5, and Appendix A). For smallmouth bass, the mean numbers of fish at the river restoration evaluation sites were 16.4, 86.7, and 49 for the natural, restored, and channelized sections, respectively (see Table 5). Similar numbers were also found for all sections of the Okanagan River that my research team and I snorkel-surveyed for fish (33.9, 86.7, and 32.9 for the natural, restored, and channelized sections, respectively. See Appendix A). For the common carp, the mean numbers of fish at the river restoration evaluation sites were 0.8, 91.8, and 21.5 for the natural, restored, and channelized sections, respectively (see Table 5). Similar numbers were also found for all sections of the Okanagan River that we snorkel-surveyed for fish (6.8, 91.7, and 12.1 for the natural, restored, and channelized sections, respectively. See Appendix A). However, pumpkinseed sunfish (*Lepomis gibbosus* L. 1758) were the most common in the channelized sections (Table 4 and Appendix A). The snorkel surveys at the river restoration evaluation sites resulted in mean numbers of fish per km of 0, 0, and 1.3 for the natural, restored, and channelized sections, respectively (Table 5). Similar numbers were also found for all sections of the Okanagan River that we snorkel surveyed for fish (0, 0, and 2.1 for the natural, restored, and channelized sections, respectively. See Appendix A).

The main result of restoring meanders to the Okanagan River seems to have been the increase in overall fish numbers. The higher numbers of northern pikeminnow may be beneficial to RMRM as this fish may be a host to the mussel. This is especially important in this part of the Okanagan Valley, as the main hosts of the mussel, sculpin (*Cottus* spp.), seem to be very uncommon in the southern part of the Okanagan (For further details, see the results and discussion in the 'Host fish availability as a potential threat' section (pp. 13-17).). Similarly, the somewhat lower numbers of pumpkinseed sunfish are likely beneficial to the mussel, as this fish is known to be a specialized molluskivore. However, the higher numbers of smallmouth bass are likely detrimental to RMRM, as this piscivore (animal that eats fish) probably contributes to reduce host fish availability to the mussel. Similarly, the higher numbers of common carp are likely also detrimental to RMRM, as the carp is a known molluskivore (animal that easts mollusks) and probably eats the mussel. For further details on the impact of introduced fish species on RMRM, see the 'Introduced fish as a potential threat' section (pp. 18-23). Based on these findings, it seems that restoration of meanders to the Okanagan River has mixed effects on the mussel through its effects on the fish fauna.

In conclusion, it seems that the restoration of meanders to the Okanagan River has had a negative impact on RMRM. It has likely reduced the habitat available to the mussel, although the restored sections of the river do provide some habitat to the mussel and may provide more habitat to the mussel as time passes and the substrate stabilizes. Despite this, it is unlikely that these restored sections will provide as good a habitat for the mussel as the channelized sections of the river. However, restoration practices can be improved in such a way as to increase the mussel's habitat in both past and future restorations. The impact of the restoration on RMRM through the interaction between the mussel and various fish species is less clear. It may provide more habitat for a potential host fish, but the successful completion of an infection experiment is necessary to determine whether this is the case. In addition, the restoration seems to provide more habitat for two introduced fish species, which are very likely to have a negative impact on the mussel.

Based on these findings, I would recommend that high value habitat in the Okanagan River should be protected from modifications that may impact the necessary habitat features for RMRM. Areas of special importance include the sections between Vaseux Lake and McIntyre Dam, and sections between the pedestrian bridge in Oliver and Osoyoos Lake. For further details on the densest mussel beds in the river, see Table 12A&B in Appendix B. If further restoration of meanders were to take place, I would recommend that special care would be taken to maximize habitat availability to the mussel in the restored sections. I also recommend augmenting restored sections and some of the channelized sections to increase the available RMRM habitat. For further details on how to improve restoration and augmentation practices, see discussion in previous paragraphs. Finally, I recommend that further studies should be undertaken to determine how the RMRM habitat can be maximized during such restorations.

Mitigating direct damage from the public

Introduction

A fourth, known, threat to Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) is direct damage to the mussels by the public. The public may damage the mussels directly through numerous activities: 1. People may collect the mussels for consumption (Jerry Mitchell *Pers. com.*). 2. Kids may collect the mussels for fun, and crush them (*Pers. obs.*) or displace them when replacing them in the water (Fisheries and Oceans Canada 2010). The latter is a threat to the mussel as it has a very narrow habitat range when it comes to the depth of water it inhabits in the Okanagan (Stanton *et al.* 2012, MacConnachie and Nield *In prep.*). 3. Fishermen may catch the mussels when fishing, as freshwater mussels are known to clamp on to lures (Per Jakobsen *Pers. com.*). Therefore, it is important to inform the public users of the waters in the Okanagan of the biology and conservations needs of RMRM. As a part of this project, we tried to increase the availability of such information to the public.

Methods

Design, production, and erection of Rocky Mountain ridged mussel interpretive signage

To reduce the risk of the public users of the waters in the Okanagan Valley doing direct harm to RMRM, it is important to provide these users with information on the biology and conservation needs of the mussel. This will be achieved through interpretive signage, focusing on the biology and conservation needs of the mussel. Such signage has been placed at six sites in the Okanagan Valley, which have high densities of mussels and are used extensively by the public. These sites are: 1. Kin Beach, Vernon, Vernon Arm of Okanagan Lake. 2. Peach Orchard Beach, Summerland, Okanagan Lake. 3. Kinsmen Park, Summerland, Okanagan Lake. 4. Three Mile Beach, Penticton, Okanagan Lake. 5. Vaseux Lake Campsite, Oliver, Vaseux Lake. 6. Oliver Skate Park, Oliver, Okanagan River. See Figure 3, for overview of sites. This

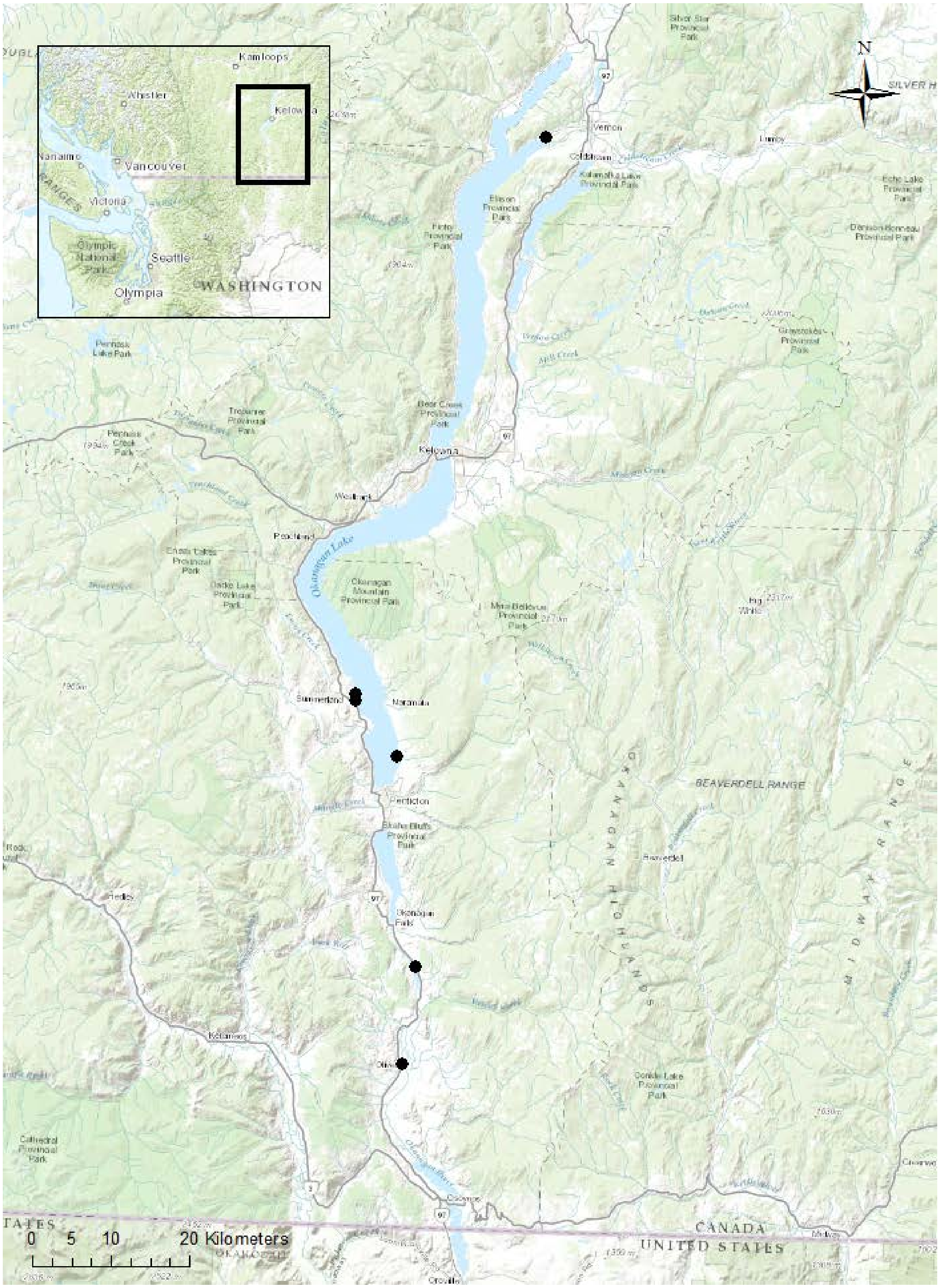

Figure 3 Location of Rocky Mountain ridged mussel interpretive signs. ● indicates the locations of the interpretive signage. (Source: ESRI.)

figure was produced using ArcMap 10.3.1 (ESRI 2014). In addition, interpretive posters have been produced, based on the signage. These posters have been/will be distributed to schools, dive shops, and other facilities catering to users of the lakes and rivers in the Okanagan Valley.

Evaluation of impact of Rocky Mountain ridged mussel interpretive signage

To evaluate the impact of the RMRM interpretive signage on the knowledge of the mussel, among users of the sites, my research team and I undertook public interviews at the six sites where the signs have been placed. The interviews were designed to evaluate the users' knowledge of the biology and the conservation needs, and the impact of the signage on this knowledge. Further, they were designed to evaluate whether the knowledge and impact differed depending on how frequent the interviewee used the site and whether they were locals or visitors. For the interview questions, see Appendix C.

The interviews were completed between September 4^{th} and 11^{th}, 2015, and we spent at least four hours at each site. I chose to complete the interviews during the latter part of the season, to let people get familiar with them. Unfortunately, the interviews were delayed by about a month, which resulted in their completion after the main tourist season was over in the Okanagan Valley. We had to delay the interviews due to a combination of bad weather and fires in the direct vicinity of some of the signs. The fires both directly threatened some of the locations and resulted in such poor air quality that outdoor activities were not recommended.

Results

Design, production, and erection of Rocky Mountain ridged mussel interpretive signage

An interpretive sign describing RMRM biology and conservation needs was developed through collaboration between Lime Design Inc., the British Columbia Ministry of Forests, Lands, and Natural

Figure 4 Rocky Mountain ridged mussel interpretive sign. Designed by Matthias Reinicke (Lime Design. Inc.), illustrated by Briony Penn (for Lime Design. Inc.), and developed in cooperation by Matthias Reinicke, Jamie Leathem (MFLNRO), Jon Mageroy (UBCO), Lora Nield (MFLNRO), Sean MacConnachie (DFO), and Martin Nantel (DFO).

Resource Operations (MFLNRO), the University of British Columbia (UBCO), and the Canadian Department of Fisheries and Oceans (DFO) (see Figure 4). The signs were produced and placed at the six sites, described in the methodology, during April and May 2015. They inform public users of Okanagan lakes and rivers about the mussel and hopefully mitigate any negative impact of such use on the mussel. In addition, 1000 posters based on the sign have also been produced. These posters have been/will be distributed to schools, dive shops, and other facilities catering to users of the lakes and rivers in the Okanagan Valley.

Table 6 Evaluation of knowledge about Rocky Mountain ridged mussel biology and conservation needs among different user groups. * indicates that these percentages are among the interviewees who knew about RMRM. ** indicates that these percentages are among the interviewees who had seen the sign. *** indicates that these percentages are among the interviewees who had read the sign. 'NA' indicates that n was too low (<10) for the answers to be included in the table.

Site	Knew About Native Freshwater Mussels	Knew About RMRM	Seen Sign	Knew About RMRM From Sign*	Read Sign**	Learned From Sign***
Overall	42.8 %	17.2 %	33.1 %	38.7 %	68.8 %	81.1 %
Visitors	27.3 %	6.8 %	20.5 %	33.3 %	NA	NA
Locals	49.5 %	21.8 %	38.6 %	50.0 %	76.9 %	80.0 %
Infrequent Users	34.1 %	8.8 %	22.0 %	50.0 %	45.0 %	NA
Frequent Users	60.0 %	28.6 %	42.9 %	35.7 %	73.3 %	100.0 %
Very Frequent Users	52.6 %	36.8 %	68.4 %	42.9 %	84.6 %	72.7 %

Table 7 Evaluation of knowledge about Rocky Mountain ridged mussel biology and conservation needs among users of the different sites with signage. Kinsmen Park was excluded from the table due to only six people being interviewed. * indicates that these percentages are among the interviewees who knew about RMRM. ** indicates that these percentages are among the interviewees who had seen the sign. *** indicates that these percentages are among the interviewees who had read the sign. 'NA' indicates that n was too low (<10) for the answers to be included in the table.

Site	Knew About Native Freshwater Mussels	Knew About RMRM	Seen Sign	Knew About RMRM From Sign*	Read Sign**	Learned From Sign***
Overall	42.8 %	17.2 %	33.1 %	38.7 %	68.8 %	81.1 %
Kin Beach, Vernon, Okanagan Lake	31.6 %	10.5 %	23.7 %	NA	NA	NA
Peach Orchard Beach, Summerland, Okanagan Lake	61.8 %	29.4 %	50.0 %	80.0 %	82.4 %	78.6 %
Three Mile Beach, Penticton, Okanagan Lake	36.1 %	8.3 %	16.7 %	NA	NA	NA
Vaseux Lake Campsite, Oliver, Vaseux Lake	73.3 %	26.7 %	33.3 %	NA	NA	NA
Oliver Skate Park, Oliver, Okanagan River	31.3 %	25.0 %	43.4 %	NA	NA	NA

Evaluation of impact of Rocky Mountain ridged mussel interpretive signage

Overall, my research team and I interviewed 145 users of the sites with RMRM interpretive signage. Table 6 reports on differences in knowledge between different user groups of the sites with interpretive signage, while Table 7 reports on differences in knowledge among sites. For a more detailed analysis of the interviewees responses, see Appendix C.

Discussion

Overall, it is positive that 42.8 % of the interviewees knew about native freshwater mussels, but it is somewhat disappointing that only 17.2 % knew about RMRM (see Tables 6 or 7). It is also somewhat disappointing that only 33.1 % had seen the sign. However, it is positive that 68.8 % of those who had seen the sign read it and that 81.1 % of those who read it learned something from it. Most importantly, the signs seem to have contributed to increased awareness of RMRM, as 38.7 % of those who knew about the mussel knew about it from the sign.

Not surprisingly, more locals knew about native freshwater mussels, knew about RMRM, had seen the sign, had read the sign, and knew about RMRM from the sign compared to visitors (see Table 6). The trend was also very similar when comparing infrequent, frequent, and very frequent users of the sites (see Table 6). The only exception was that among people who knew about RMRM, more of the infrequent users knew about it from the sign. This is maybe to be expected as frequent and very frequent users of the sites would be more likely to see the mussels, to have heard about them from other users, and/or to have encountered researchers working at the sites. However, one should consider the fact that the interviews occurred after the main tourist season in the Okanagan Valley. Therefore, both visitors and infrequent users are probably underrepresented among the interviewees. Accordingly, my results probably overestimate the awareness of native freshwater mussels and RMRM among users of these sites. Similarly, they also probably overestimate the percentage who had seen the sign and read the sign. Even so, my data show that the signs have been important in contributing to the awareness of RMRM among both visitors and infrequent users of the sites.

My results show that the awareness of native freshwater mussels and RMRM is greatest among users of Peach Orchard Beach and Vaseux Lake Campsite (see Table 7). That users of Peach Orchard Beach were more aware is not surprising since many people go swimming at this site, research has been going on at this site frequently for several years, there have been stories about the mussels in the media, guided nature tours include information on the mussels, and there are school programs about the mussels. In addition, my data show that the sign is contributing extensively to the awareness, as 50 % of users had seen the sign and 80 % of those who knew about RMRM knew about it from the sign. That users of Vaseux Lake Campsite were more aware is probably explained by the fact that most users of this site camp there for several days and have extensive opportunities to discover the mussels. However, my data show that the placement of the sign probably could have been better, as only 33.3 % of users had seen the sign despite the fact that users stay here for several days. The relatively high level of awareness of RMRM, despite the lack of awareness of native freshwater mussels, at the Oliver Skate Park is probably explained by people seeing the signs, as there has been limited research and other focus on the mussel at this location. The low levels of awareness at Kin Beach and Three Mile Beach is probably due to the limited research and other focus on the mussel at these locations. However, my data also show that the placement of the signs at these locations probably could have been better, as less than 25 % had seen the sign. Alternatively, there could maybe have been two signs at each of these sites, as Kin Beach is a long beach and Three Mile Beach has two distinct user areas while the sign is placed in-between them.

In conclusion, the awareness of RMRM is very low among users of the high density mussel sites in the Okanagan Valley. However, my data show that the signs have increased this awareness by about 50 %. In addition, the signs have contributed extensively to knowledge about the biology and conservation needs of RMRM among those who read the signs. These findings are valid for all user groups, although visitors and infrequent users were less likely to see the signs. The relatively low percentage of users who had seen the signs suggest that the placement of the signs could have been better, especially at Kin Beach and Three Mile Beach. However, overall the signs have increased the awareness of RMRM among users at the high density mussel beds in the Okanagan and should continue to do so as more and more users see and read them, over the coming years. Therefore, it is likely that the signs contribute to the mitigation of direct damage to the mussel at these sites. Further, I would recommend adding signs to newly discovered high density RMRM beds (see Appendix B for an overview of beds discovered during this project) and adding additional signs to some of the known high density mussel beds, especially Kin Beach and Three Mile Beach.

Conclusions and Recommendations

Despite the unsuccessful nature of the host fish infection experiment, I can make several conclusions about the threats to the Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) in the Okanagan Valley. Using data from experiments in the US (Spring Rivers 2007, O'Brien *et al.* 2013, Alexa Maine *Pers. com.*) and field work in the Okanagan (Stanton *et al.* 2012, Mageroy 2015), it is possible to conclude, with a high level of certainty, that sculpin (*Cottus* spp.) are the primary hosts for the mussel in the system. In addition, the field data (Stanton *et al.* 2012, Mageroy 2015) show that northern pikeminnow (*Ptychocheilus oregonensis*, Richardson 1836), and leopard (*Rhinichthys falcatus* Eigenmann and Eigenmann 1893) and longnose dace (*Rhinichthys cataractae*, Valenciennes 1842) are potential hosts. Given these findings and my data on fish presence and relative abundance at the high density RMRM beds in the Okanagan, it is possible to conclude that limited availability of host fish is not currently a threat to the mussel in Okanagan Lake. However, the data suggest that it is a threat to the mussel in the southern Okanagan Valley.

My data, on introduced fish species, show that this reduced host fish availability is probably due to the introduction of smallmouth bass (*Micropterus dolomieu*, Lacepede 1802) into the southern part of the system. The fact that this fish species has recently been found in Okanagan Lake (Jerry Mitchell, *Pers. com.*) is of particular concern. If it becomes established in the lake in large numbers is likely to reduce the host availability to RMRM in the lake. Other introduced fish are also likely a threat to the mussel as molluskivores (animals that eat mollusks), as both common carp (*Cyprinus carpio*, L. 1758) and pumpkinseed sunfish (*Lepomis gibbosus* L. 1758) are present at many of the high density mussel beds in the Okanagan Valley. Therefore, it is safe to conclude that introduced fish species are a threat to the mussel in this system.

It was also possible to evaluate the impact of restoration of meanders to the Okanagan River on RMRM. The data show that RMRM are by far the most common in the channelized sections of the river, while restored and natural sections of the river have very limited habitat value to the mussel. Therefore, it is safe to conclude that past restoration has reduced the habitat available to RMRM. However, it is possible to improve restoration practices to maximize the habitat availability to the mussel in restored sections. It is also possible to augment past restorations and channelized sections of the river to increase habitat availability. The impact of the restoration on RMRM through its effect on fish fauna is less clear.

The data show that the restored areas have higher numbers of one of the potential hosts (northern pikeminnow), and of smallmouth bass and the common carp (both are very likely to have a negative impact on RMRM). Therefore, it is not easy to conclude whether restoration of meanders affects fish habitat in a way that is negative or positive for the mussel. However, overall restoration of meanders to the Okanagan River clearly has had a negative impact on RMRM. Any further restorations should be undertaken in such a way as to negate such a negative impact.

Unfortunately, the interview data show that awareness of RMRM is very low among users of the shoreline associated with high density mussel beds in the Okanagan Valley. However, the placement of interpretive signage, at some of these sites, has improved the awareness and knowledge about the mussel among users. These findings were valid among all groups of users and among all sites. Even so, the data showed that at some of the sites the placement of the signs was not ideal. Overall, these findings show that the signs have increased the knowledge of RMRM and they should continue to do so in the future. Therefore, it is likely that the signs contribute to the mitigation of direct damage to the mussel at these sites.

Based on the findings on fish from this project, I can make several recommendations: I recommend investigating if juvenile recruitment is sufficient to maintain RMRM numbers at the mussel beds in the southern Okanagan, which would determine if lack of recruitment is a threat to the mussel in this part of the system. If recruitment is insufficient to maintain mussel numbers, one knows that host fish availability may be a threat to the mussel. In addition, I recommend completing the host fish infection experiment. Although it is very likely that sculpin are the primary hosts for RMRM, the secondary hosts have not been confirmed in the Okanagan Valley. In addition, it is also important to determine whether any introduced fish can serve as hosts for the mussel. Confirming if any fish, other than sculpin, can serves as hosts for RMRM would contribute to increased certainty with respect to the conclusions related to threats from limited host availability, threats from introduced fish species, and the impact of restoration of meanders to the Okanagan River on the fish fauna. I also recommend additional fish sampling and surveying, which would also strengthen these conclusions.

Despite this uncertainty, it is clear that smallmouth bass, common carp, and pumpkinseed sunfish are very likely to negatively impact RMRM. Therefore, taking actions to limit/reduce their numbers in the Okanagan could assist in the recovery of the mussel population. One such measure would be to prevent further modifications of dams to allow fish passage upriver in the system, which could allow introduced fish to colonize new parts of the system. However, for smallmouth bass this point may already be inconsequential, as this species has recently been found in Okanagan Lake (Jerry Mitchell, *Pers. com.*). Another measure could be to eliminate any restrictions on fishing for the three species mentioned above.

Based on the findings on the impact of restoring meanders to the Okanagan River, I can make several recommendations: I recommend that high value habitat in the Okanagan River should be protected from modifications that may impact the necessary habitat features for the mussel. If further restoration of meanders were to take place, I recommend that special care would be taken to maximize habitat availability to the mussel in the restored sections. I also recommend augmenting previously restored sections and some of the channelized sections to increase the available RMRM habitat. In addition, I recommend that further studies should be undertaken to determine how the RMRM habitat can be maximized during such restorations.

Finally, the RMRM interview data show that the awareness of and the knowledge about the mussel is low, but that the signs greatly improve the level of awareness and knowledge. In addition, the data also show that some of the sites could use additional signage. Further, my research team and I have also found more high density mussel beds through this project. Therefore, I recommend placing additional signage at some of the previously known and some of the recently discovered high density RMRM beds in the Okanagan Valley.

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Appendices

Appendix A: Complete overview of fish data

Methods

The fish data summarized in this appendix include all fish data on all species of fish collected at all sites during this project. This means that data on additional fish species have been added for the sites reported on in the main text. In addition, several more sites have been added for the Okanagan River. The survey and sampling methods are the same as described in the 'Fish surveying and sampling' methodologies in the 'Host fish availability as a potential threat' (pp. 10-11) and 'River restoration as a potential threat' (p. 26) sections in the main text. All sampling and surveying was completed between June 9th and July 8th, 2015. For an overview of fish sampling and survey locations associated with high density Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) beds and river restoration evaluation sites, see Figure 1 ('Host fish as a potential threat' section, p. 12) and Figure 2 ('River restoration as a potential threat' section, p. 25) in the main text, respectively. For an overview of all snorkel survey locations, see Figure 5 below. This figure was produced using ArcMap 10.3.1 (ESRI 2014).

Results

In addition to reporting on the findings of the fish species reported on in the main text, this appendix reports on findings of: Lake chub (*Couesius plumbeus*, Agassiz 1850), largescale sucker (*Catostomus macrocheilus*, Girard 1856), mountain whitefish (*Prosopium williamsoni*, Girard 1856), peamouth chub (*Mylocheilus caurinus*, Richardson 1836), rainbow trout (*Oncorhynchus mykiss*, Walbaum 1792), and redside shiner (*Richardsonius balteatus*, Richardson 1836). Table 8 reports on all fish data from this project for each of the known high density RMRM beds, reported on in the main text. Tables 9 and 10 report on all fish data from snorkel surveys of the Okanagan River. The former reports on the fish data for each site, while the latter reports on the mean number of each fish species per km of natural, restored, and channelized section of the river. Table 11 reports on all fish data from minnow traps on the Okanagan River.

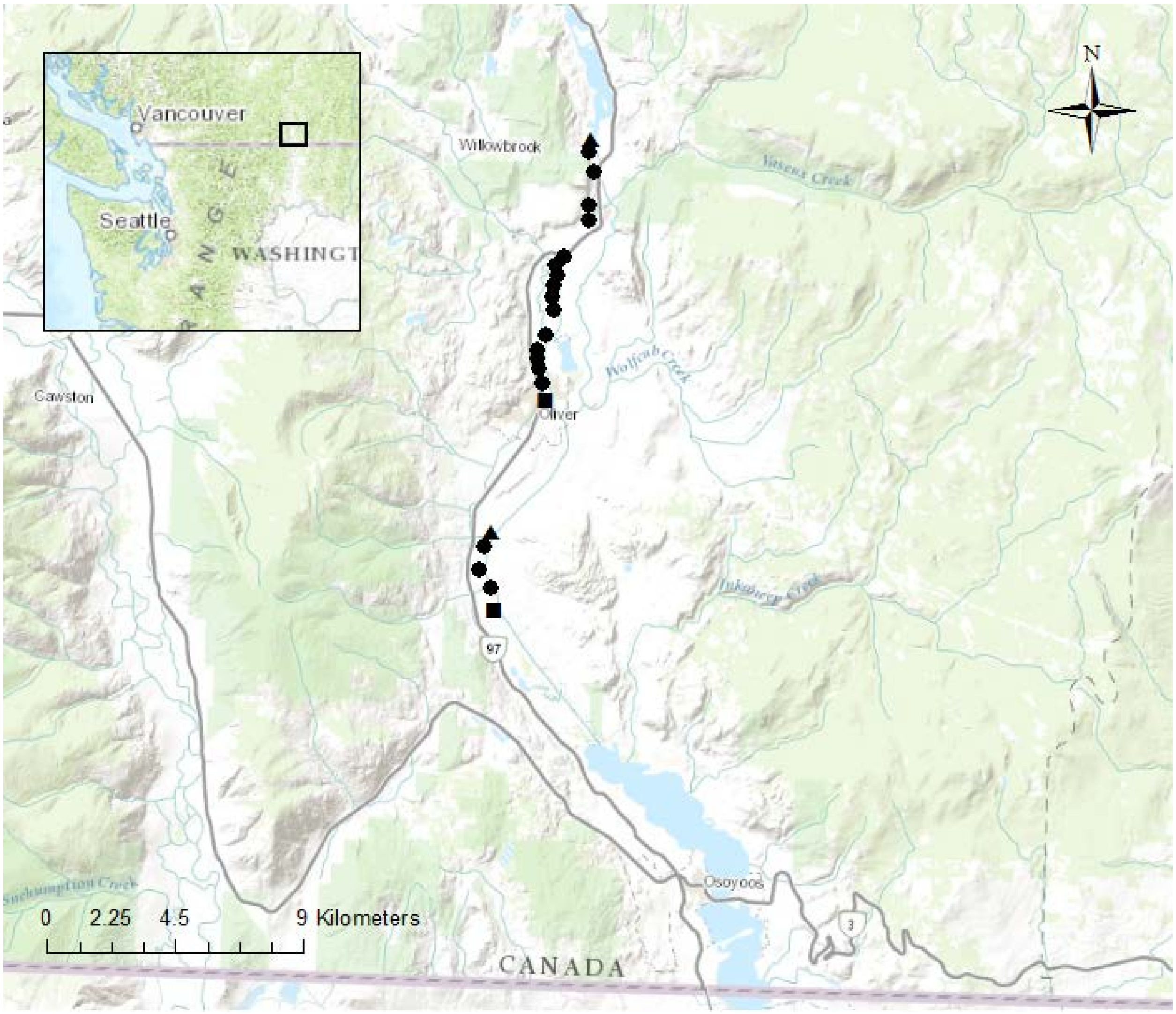

Figure 5 Overall fish snorkel survey locations. The map shows the two parts of the Okanagan River that were snorkel surveyed for fish presence and relative abundance. ▲ indicates the start of each survey. ● indicates nodes within a survey, i.e. data were recorded for each section of the river that is between two nodes. Note that some nodes were excluded from the map, for visualization reasons. ■ indicates the end of each survey (Source: ESRI.)

Table 8 Overall fish data for high density Rocky Mountain ridged mussel beds. The data for Dog Beach and Kinsmen Park in Summerland come from Mageroy (2015), although the actual numbers are based on base data not shown in that report. NA indicates that the method was not used at the site. * indicates that the number of fish has been adjusted to account for sampling effort in the form of days sampled and traps set. ** indicates that the number of fish has been adjusted to account for sampling effort in the form of days sampled. The adjustments were made to make the fish numbers comparable among sites.

Site	Minnow Traps	Gill Net	Beach Seine	Snorkel Survey
Kin Beach, Vernon Arm, Okanagan Lake	11 northern pikeminnow 6 prickly sculpin 1 pumpkinseed sunfish	34 northern pikeminnow 31 yellow perch 18 peamouth chub 12 largescale suckers 4 redside shiners 4 rainbow trout 1 prickly sculpin 1 common carp	NA	NA
Dog Beach, Summerland, Okanagan Lake	8 prickly sclupin*	4 mountain whitefish 1 sucker	19 mountain whitefish** 15 prickly sculpin** 2 longnose dace** 1 redside shiner**	NA
Kinsmen Park, Summerland, Okanagan Lake	4 prickly sculpin*	16 lake chub 15 northern pikeminnow 10 suckers 6 yellow perch 2 common carp 1 mountain whitefish 1 unidentified	31 prickly sculpin** 5 redside shiner** 4 longnose dace** 2 lake chub** 1 mountain whitefish**	NA
Three Mile Beach, Penticton, Okanagan Lake	5 prickly sculpin	58 peamouth chub 42 largescale suckers 27 northern pikeminnow 14 redside shiners 2 mountain whitefish 2 prickly sculpin	NA	NA
Vaseux Lake Campsite, Oliver, Vaseux Lake	1 yellow perch	20 smallmouth bass 9 largescale suckers 6 pumpkinseed sunfish 6 yellow perch 5 brown bullheads 4 northern pikeminnow 2 largemouth bass 2 common carp 1 black crappie 1 peamouth chub	17 smallmouth bass 2 pumpkinseed sunfish 1 rainbow trout 1 prickly sculpin	NA
Fairview Rd. Bridge, Oliver, Okanagan River	2 pumpkinseed sunfish	NA	NA	50 smallmouth bass 20 suckers 18 common carp 3 pumpkinseed sunfish 2 northern pikeminnow 1 rainbow trout
# 9 Rd. bridge, Oliver, Okanagan River	3 smallmouth bass 2 brown bullheads	NA	NA	16 smallmouth bass 11 common carp 2 unidentified
# 18 Rd. bridge, Oliver, Okanagan River	3 smallmouth bass	NA	NA	7 smallmouth bass 3 common carp

Table 9A Overall fish data for snorkel surveys on the Okanagan River. The survey is primarily continuous from start to finish. Therefore, the downstream UTM of the site in question is the upstream UTM for the next site. * indicates when this is not the case and the downstream UTM for that particular site has been included, following the upstream UTM.

River Type	Start Site	Upstream UTM	Fish	Survey Length (km)
Channelized	Vaseux Lake	11 U 315893 5460233	15 yellow perch 6 pumpkinseed sunfish 3 smallmouth bass 3 largemouth bass 3 common carp	0.50
	McIntyre Scree	11 U 315851 5459756	11 common carp 7 smallmouth bass 2 pumpkinseed sunfish	0.69
Natural	McIntyre Dam	11 U 316031 5459087	45 smallmouth bass 9 suckers 4 salmonids 3 northern pikeminnow 2 common carp	1.26
	Deer Park Estates	11 U 315869 5457893	4 smallmouth bass	0.58
	Gallagher Lake Development	11 U 315862 5457345	41 smallmouth bass 9 suckers 6 salmonids 4 northern pikeminnow 1 common carp	1.72
	Highway Bridge	11 U 314959 5456085	90 suckers 18 common carp 13 smallmouth bass 2 salmonids	0.61
	First Confluence	11 U 314755 5455589	30 smallmouth bass 10 suckers 10 common carp	0.91
	Triple Split	11 U 314573 5454709	61 smallmouth bass 15 suckers 13 northern pikeminnow 8 common carp 3 salmonids	0.64
Channelized	Last Confluence	11 U 314644 5454110, 11 U 314343 5453315*	27 smallmouth bass 25 suckers 8 common carp 2 salmonids	0.85

Table 9B Overall fish data for snorkel surveys on the Okanagan River - Continued.

River Type	Start Site	Upstream UTM	Fish	Survey Length (km)
Restored	Spawning Channel	11 U 314343 5453315, 11 U 314272 5453179*	4 smallmouth bass 1 northern pikeminnow	0.23
Channelized	Riffle	11 U 314343 5453315	26 smallmouth bass 11 suckers 3 common carp 1 prickly sculpin 1 northern pikeminnow	0.52
Restored	Northern Restored Meander	11 U 314050 5452836	32 smallmouth bass 17 northern pikeminnow 4 common carp 2 suckers	0.19
	Southern Restored Meander	11 U 314033 5452543	51 common carp 16 smallmouth bass 8 northern pikeminnow 7 suckers	0.18
Channelized	Weir # 13	11 U 314115 5452194	63 smallmouth bass 13 common carp 3 pumpkinseed sunfish 1 sucker	0.58
	Pedestrian Bridge	11 U 314232 5451627, 11 U 314361 5451058*	50 smallmouth bass 20 suckers 18 common carp 3 pumpkinseed sunfish 2 northern pikeminnow 1 salmonid	0.58
	# 9 Rd. Bridge	11 U 312431 5446453	16 smallmouth bass 11 common carp 2 unidentified	0.56
	1st Bend	11 U 312190 5445957	9 smallmouth bass 6 common carp	0.85
	2nd Bend	11 U 312022 5445138	5 smallmouth bass 1 common carp	0.63
	Weir # 5	11 U 312389 5444483	10 smallmouth bass 6 northern pikeminnow 5 common carp	0.66
	Weir # 4	11 U 312520 5443740, 11 U 312685 5443430*	7 smallmouth bass 3 common carp	0.35

Table 10 Overall mean number of each fish species per km of the Okanagan River. These data are from snorkel surveys, as they are the only surveys that have survey lengths associated with them.

Fish Species	River Type	Fish Number	Survey Length (km)	Fish/km
Prickly sculpin	Natural	0	5.72	0
	Restored	0	0.60	0
	Channelized	1	6.77	0.1
Northern pikeminnow	Natural	20	5.72	3.5
	Restored	26	0.60	43.3
	Channelized	9	6.77	1.3
Suckers	Natural	143	5.72	25
	Restored	9	0.60	15
	Channelized	47	6.77	6.9
Salmonids	Natural	15	5.72	2.6
	Restored	0	0.60	0
	Channelized	3	6.77	0.4
Smallmouth bass	Natural	194	5.72	33.9
	Restored	52	0.60	86.7
	Channelized	223	6.77	32.9
Largemouth bass	Natural	0	5.72	0
	Restored	0	0.60	0
	Channelized	3	6.77	0.4
Common carp	Natural	39	5.72	6.8
	Restored	55	0.60	91.7
	Channelized	82	6.77	12.1
Pumpkinseed sunfish	Natural	0	5.72	0
	Restored	0	0.60	0
	Channelized	14	6.77	2.1
Yellow perch	Natural	0	5.72	0
	Restored	0	0.60	0
	Channelized	15	6.77	2.2

Table 11 Overall fish data for minnow traps on the Okanagan River.

River Type	Site	UTM	Fish
Natural	McIntyre Dam	11 U 316056 5458931	1 smallmouth bass
	Gallagher Lake Development	11 U 315857 5457857	1 rainbow trout
	Highway Bridge	11 U 314959 5456085	2 smallmouth bass 1 prickly sculpin
Restored	Spawning Channel	11 U 314276 5453181	2 suckers 1 smallmouth bass 1 pumpkinseed sunfish 1 yellow perch 1 northern pikeminnow
	Northern Restored Meander	11 U 313984 5452746	2 smallmouth bass 1 pumpkinseed sunfish
	Southern Restored Meander	11 U 314007 5452475	1 smallmouth bass
Channelized	Fairview Rd. Bridge	11 U 314357 5451119	2 pumpkinseed sunfish
	# 9 Rd. Bridge	11 U 312395 5446391	3 smallmouth bass 2 brown bullheads
	# 18 Rd. Bridge	11 U 314865 5440499	3 smallmouth bass

Appendix B: Complete overview of mussel surveys

Methods

The mussel data summarized in this appendix include all mussel data on all species of mussels collected at all sites during 2015. This means that it includes data on all mussel species for the sites reported on in the ‘Mussel surveys’ results in the ‘River restoration as a potential threat’ section of the main text (p. 27), but it also includes the data from additional mussel surveys that were completed during the project. Most of these surveys were completed by snorkeling and according to the ‘Mussel surveys’ methods described in the ‘River restoration as a potential threat’ section (p. 26). However, one snorkel survey was completed in Okanagan Lake. For this survey, the surveyors followed a grid pattern to maximize the coverage of the area. Additional surveys were completed by walking the bank, looking for shells, or wading the stream channel, looking for mussels on the river bottom by using polarized glasses. Other surveys were completed by a combination of wading and snorkeling, or a combination of walking the bank, snorkeling, and wading. The method of survey is indicated for each site in the results section. All surveys, with the exception of the surveys completed in 2013, were completed between July 3rd and August 11th, 2015. For overview of all survey locations, see Figure 6. This figure was produced using ArcMap 10.3.1 (ESRI 2014).

Results

Table 12 reports on all the Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) data from surveys on the Okanagan River between Vaseux Lake and Osoyoos Lake. For all surveys on this section of the river the mean number of RMRM per km were 0.3, 6.7, and 111.8 for the natural, restored, and channelized sections, respectively. Table 13 reports on all RMRM data from surveys elsewhere in the Okanagan Valley, completed during 2015. Table 14 reports on all data for other mussel species, from 2015.

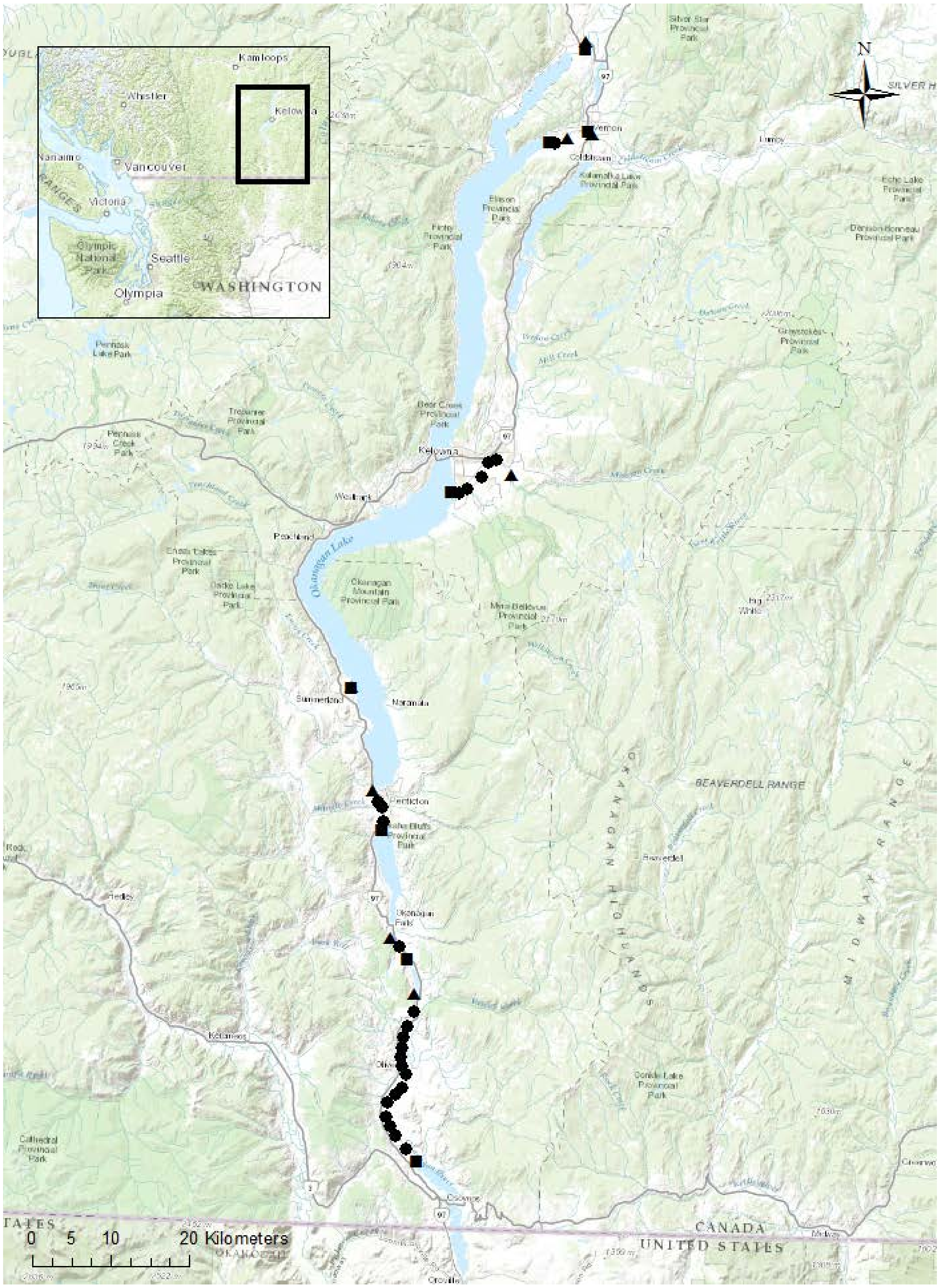

Figure 6 Overall mussel survey locations. The map shows all RMRM surveys completed during 2015 and five sections surveyed during 2013. ▲ indicates the start of each survey. ● indicates nodes within a survey, i.e. data were recorded for each section of the river that is between two nodes. Note that several nodes were excluded from the map, for visualization reasons. ■ indicates the end of each survey. (Source: ESRI.)

Table 12A Okanagan River Rocky Mountain ridged mussel data. This table shows results for surveys for RMRM in the Okanagan River between Vaseux and Osoyoos Lakes. All surveys were snorkel surveys. * indicates that the data are from surveys completed in 2013 (*Unpubl. data*).

Water Body Type	Site	Upstream UTM	Downstream UTM	RMRM Numbers	Survey Length (km)	RMRM /km
Channelized	Southern Vaseux Lagoon to McIntyre Dam	11 U 315893 5460233	11 U 316031 5459087	32	1.19	26.9
Natural	McIntyre Dame to Deer Park Estates	11 U 316031 5459087	11 U 315869 5457893	0	1.26	0
	Deer Park Estates to Gallagher Lake Development	11 U 315869 5457893	11 U 315862 5457345	0	0.58	0
	Gallagher Lake Development to Highway Bridge	11 U 315862 5457345	11 U 314959 5456085	1	1.72	0.6
	Highway Bridge to 1st Bend	11 U 314959 5456085	11 U 314843 5455847	0	0.28	0
	1st Bend to 1st Fork	11 U 314843 5455847	11 U 314700 5455768	0	0.15	0
	1st Fork to 1st Confluence	11 U 314700 5455768	11 U 314755 5455589	0	0.18	0
	1st Confluence to 2nd Confluence	11 U 314755 5455589	11 U 314759 5455456	0	0.14	0
	2nd Confluence to Triple Split	11 U 314759 5455456	11 U 314683 5455223	0	0.25	0
	Triple Split to 3rd Confluence	11 U 314683 5455223	11 U 314654 5455117	1	0.10	10
	3rd Confluence to 2nd Triple Split	11 U 314654 5455117	11 U 314573 5454709	0	0.42	0
	2nd Triple Split to 4th Confluence	11 U 314573 5454709	11 U 314594 5454588	0	0.12	0
	4th Confluence to Power Line	11 U 314594 5454588	11 U 314560 5454409	0	0.18	0
	Power Line to 3rd Triple Split	11 U 314560 5454409	11 U 314651 5454232	0	0.20	0
	3rd Triple Split to Channelized Section	11 U 314651 5454232	11 U 314644 5454110	0	0.14	0
Channelized	Channelized Section to Spawning Channel	11 U 314644 5454110	11 U 314343 5453315	0	0.85	0
Restored	Spawning Channel	11 U 314343 5453315	11 U314272 5453179	0	0.23	0

Table 12B Okanagan River Rocky Mountain ridged mussel data - Continued.

Water Body Type	Site	Upstream UTM	Downstream UTM	RMRM Numbers	Survey Length (km)	RMRM /km
Channelized	Spawning Channel to Northern Restored Meander	11 U 314343 5453315	11 U 314050 5452836	5	0.52	9.6
Restored	Northern Restored Meander	11 U 314050 5452836	11 U 314010 5452706	0	0.19	0
	Southern Restored Meander	11 U 314033 5452543	11 U 314042 5452405	4	0.18	22.2
Channelized	Weir # 13 to Pedestrian Bridge*	11 U 314115 5452194	11 U 314232 5451627	84	0.58	144.8
	Pedestrian Bridge to Fairview Rd. Bridge*	11 U 314232 5451627	11 U 314361 5451058	369	0.58	636.2
	Fairview Rd. Bridge to Weir # 11	11 U 314361 5451058	11 U 314880 5449987	46	1.11	41.4
	Weir # 11 to Weir # 10	11 U 314880 5449987	11 U 314729 5448978	63	1.07	58.9
	Weir # 10 to Thorpe Rd. Bridge	11 U 314729 5448978	11 U 314292 5448306	71	0.80	88.8
	Thorpe Rd. Bridge to Weir # 8	11 U 314292 5448306	11 U 313525 5447532	162	1.09	148.6
	Weir # 8 to Weir # 7	11 U 313525 5447532	11 U 312777 5446789	83	1.06	78.3
	Weir # 7 to # 9 Rd. Bridge	11 U 312777 5446789	11 U 312509 5446515	12	0.38	31.6
	# 9 Rd. Bridge to Weir # 5*	11 U 312509 5446515	11 U 312361 5444522	252	2.22	113.5
	Weir # 5 to Weir # 4*	11 U 312361 5444522	11 U 312511 5443763	297	0.78	380.8
	Weir # 4 to # 18 Rd. Bridge*	11 U 312511 5443763	11 U 312742 5443345	46	0.49	93.9
	# 18 Rd. Bridge to Weir # 2	11 U 312742 5443345	11 U 313501 5442262	150	1.32	113.6
	Weir # 2 to # 22 Rd. Bridge	11 U 313501 5442262	11 U 314903 5440465	160	2.28	70.2
	# 22 Rd. Bridge to Weir # 1	11 U 314903 5440465	11 U 315243 5440058	111	0.53	209.4
	Weir # 1 to Osoyoos Lake	11 U 315243 5440058	11 U 316119 5438962	99	1.41	70.2

Table 13A Other Okanagan Valley Rocky Mountain ridged mussel data. This table shows results for surveys for RMRM in the Okanagan Valley in 2015, other than the surveys in the Okanagan River between Vaseux and Osoyoos Lakes. Most surveys were snorkel surveys. * indicates that the surveys were completed by wading. ** Indicates that the surveys were completed by a combination of wading and snorkeling. *** Indicates that above KLO Rd. Bridge the surveys were completed by a combination of walking the creek bank, wading, and snorkeling, while below KLO Rd. Bridge the surveys were completed by snorkeling. **** indicates that the surveys were completed by walking the creek bank.

Water Body	Site	Upstream UTM	Downstream UTM	RMRM Numbers	Survey Length (km)	RMRM /km
Deep Creek*	2nd Hole Tee to 6th Hole Green Bridge	11 U 337663 5581446	11 U 337866 5581297	0	0.30	0
	6th Hole Green Bridge to 13th Hole Tee	11 U 337866 5581297	11 U 337845 5580909	0	0.45	0
	13th Hole Tee to 13th to 16th Hole Bridge	11 U 337845 5580909	11 U 337732 5580467	0	0.60	0
Lower Vernon Creek**	Polson Park: Eastern End to 1st Bridge	11 U 338436 5569594	11 U 338326 5569628	0	0.11	0
	Polson Park: 1st Bridge to 3rd Bridge	11 U 338326 5569628	11 U 338128 5569736	0	0.24	0
	Polson Park: 3rd Bridge to 5th Bridge	11 U 338128 5569736	11 U 337978 5569887	0	0.20	0
	Polson Park: 5th Bridge to 6th Bridge	11 U 337978 5569887	11 U 337955 5569913	0	0.03	0
	Polson Park: 6th Bridge to Western End	11 U 337955 5569913	11 U 337928 5569979	0	0.08	0
	Clarence Fulton Secondary	11 U 335322 5569095	11 U 335225 5568899	0	0.29	0
	Ellison Elementary	11 U 335225 5568899	11 U 333106 5568499	0	0.20	0
	Marshall Field	11 U 333726 5568421	11 U 333106 5568499	0	0.83	0
Mission Creek***	E Kelowna Rd. Bridge to 1st Pedestrian Bridge	11 U 328199 5526317	11 U 326279 5528047	0	3.02	0
	1st Pedestrian Bridge to 2nd Pedestrian Bridge	11 U 326279 5528047	11 U 325386 5527763	0	0.97	0
	2nd Pedestrian Bridge to KLO Rd. Bridge	11 U 325386 5527763	11 U 324418 5526004	0	2.1	0
	KLO Rd. Bridge to Carsorso Rd. Bridge	11 U 324418 5526004	11 U 322637 5524416	0	2.44	0
	Carsorso Rd. Bridge to Gordon Dr. Bridge	11 U 322637 5524416	11 U 321522 5523933	0	1.23	0
	Gordon Dr. Bridge to Lakeshore Rd. Bridge	11 U 321522 5523933	11 U 321131 5524128	0	0.51	0
	Lakeshore Rd. Bridge to Okanagan Lake	11 U 321131 5524128	11 U 320661 5524143	0	0.48	0

Table 13B Other Okanagan Valley Rocky Mountain ridged mussel data – Continued.

Water Body	Site	Upstream UTM	Downstream UTM	RMRM Numbers	Survey Length (km)	RMRM /km
Okanagan Lake	1st Beach on N Lakeshore Dr.	11 U 307960 5499341	11 U 307965 5499267	133	0.8	166.3
Penticton Channel	Coyote Cruises to Northern Highway Bridge	11 U 310640 5486205	11 U 310528 5485868	0	0.39	0
	Northern Highway Bridge to Pedestrian Bridge	11 U 310528 5485868	11 U 310842 5485054	1	0.89	1.1
	Pedestrian Bridge to Railway Bridge	11 U 310842 5485054	11 U 311331 5484584	0	0.68	0
	Railway Bridge to Bend	11 U 311331 5484584	11 U 311630 5484294	2	0.42	4.8
	Bend to Green Mountain Rd. Bridge	11 U 311630 5484294	11 U 311830 5483933	0	0.41	0
	Green Mountain Rd. Bridge to New Bridge	11 U 311830 5483933	11 U 311957 5482122	0	1.81	0
	New Bridge to Southern Highway Bridge	11 U 311957 5482122	11 U 311759 5481087	0	1.06	0
Okanagan River Above Vaseux Lake	Weir # 15 to Weir # 14	11 U 312810 5467482	11 U 313330 5466680	1	0.96	1.0
	Weir # 14 to 1st Bend	11 U 313330 5466680	11 U 314012 5466140	2	0.88	2.3
	1st Bend to 2nd Bend	11 U 314012 5466140	11 U 314552 5465500	1	0.80	1.3
	2nd Bend to Vaseux Lake	11 U 314552 5465500	11 U 314916 5464739	0	0.89	0
Vaseux Creek*	Highway Bridge to Okanagan River	11 U 316234 5457806	11 U 315848 5457617	0	0.46	0
Park Rill Creek****	Elm Tree Bed & Breakfast	11 U 314101 5454056	11 U 314011 5454350	0	0.65	0

Table 14 Western pearlshell and floater data. This table shows survey data for western pearlshell (*Margartifera falcata*) and floaters (*Anadonta* spp.) from 2015. The floaters were not species identified due to the reigning confusion about their taxonomic status (Nedeau *et al.* 2009). Note that this table only shows the results of surveys where the numbers of these species were recorded. For some surveys completed during 2015 the numbers of floaters were not recorded, i.e. only floater presence/absence was recorded. Also note this table only shows the results of surveys that resulted in the detection of these species, i.e. surveys with no western pearlshells or floaters are not included.

Water Body	Site	Upstream UTM	Downstream UTM	Mussel Species	Mussel Numbers	Survey Length (km)	Mussels /km
Deep Creek*	2nd Hole Tee to 6th Hole Green Bridge	11 U 337663 5581446	11 U 337866 5581297	Floaters	17	0.30	56.7
	6th Hole Green Bridge to 13th Hole Tee	11 U 337866 5581297	11 U 337845 5580909		11	0.45	24.4
	13th Hole Tee to 13th to 16th Hole Bridge	11 U 337845 5580909	11 U 337732 5580467		13	0.60	21.7
Mission Creek	KLO Rd. Bridge to Carsorso Rd. Bridge	11 U 324418 5526004	11 U 322637 5524416	Western pearlshell	49	2.44	20.1
	Carsorso Rd. Bridge to Gordon Dr. Bridge	11 U 322637 5524416	11 U 321522 5523933		144	1.23	117.1
	Gordon Dr. Bridge to Lakeshore Rd. Bridge	11 U 321522 5523933	11 U 321131 5524128		211	0.51	413.7
	Lakeshore Rd. Bridge to Okanagan Lake	11 U 321131 5524128	11 U 320661 5524143		3	0.48	6.3
Penticton Channel	Green Mountain Rd. Bridge to New Bridge	11 U 311830 5483933	11 U 311957 5482122	Floaters	2	1.81	1.1
Okanagan River Above Vasuex Lake	Weir # 15 to Weir # 14	11 U 312810 5467482	11 U 313330 5466680		2	0.96	2.1
	Weir # 14 to 1st Bend	11 U 313330 5466680	11 U 314012 5466140		2	0.88	2.3
	1st Bend to 2nd Bend	11 U 314012 5466140	11 U 314552 5465500		16	0.80	20.0
	2nd Bend to Vaseux Lake	11 U 314552 5465500	11 U 314916 5464739		12	0.89	13.5
Okanagan River Below Vaseux Lake	Weir # 11 to Weir # 10	11 U 314880 5449987	11 U 314729 5448978		3	1.07	2.8
	Weir # 10 to Thorpe Rd. Bridge	11 U 314729 5448978	11 U 314292 5448306		1	0.80	1.3
	Thorpe Rd. Bridge to Weir # 8	11 U 314292 5448306	11 U 313525 5447532		4	1.09	3.7
	Weir # 8 to Weir # 7	11 U 313525 5447532	11 U 312777 5446789		2	1.06	1.9
	# 18 Rd. Bridge to Weir # 2	11 U 312742 5443345	11 U 313501 5442262		16	1.32	12.1
	Weir # 2 to # 22 Rd. Bridge	11 U 313501 5442262	11 U 314903 5440465		6	2.28	2.6
	# 22 Rd. Bridge to Weir # 1	11 U 314903 5440465	11 U 315243 5440058		10	0.53	18.9
	Weir # 1 to Osoyoos Lake	11 U 315243 5440058	11 U 316119 5438962		7	1.41	5.0

Appendix C: Rocky Mountain ridged mussel interview

Methods

Below follows the list of the questions asked during the interview on public users' knowledge of Rocky Mountain ridged mussel (RMRM; *Gonidea angulata*, Lea 1839) biology and conservation needs:

1. Are you 19 years or older?
2. Do you understand the nature of our research and do you agree to participate in this interview?
3. Where are you from?
4. If visitors, how long have you been here?
5. Have you been at this beach/campsite/park before?
6. How many times have you been to this location this summer?
7. Have you heard about freshwater mussels?
8. Have you heard about invasive freshwater mussels (quagga and zebra)?
9. Where did you hear about invasive freshwater mussels?
10. Do you know that we have native freshwater mussels in the Okanagan?
11. How did you learn about the native freshwater mussels in the Okanagan?
12. Have you heard about Rocky Mountain ridged mussels?
13. How did you learn about Rocky Mountain ridged mussels?
14. Have you seen the Rocky Mountain ridged mussel sign?
15. Did you learn something new from the sign?
16. What do you think of the sign?

Results

Table 15 gives an overview of all mussel related responses from all interviewees that took part in the RMRM interview.

Table 15 Compete overview of all mussel related responses from Rocky Mountain ridged mussel interview. This table shows the responses for all interviewees, different user groups of the sites, and different sites. * indicates that these percentages are among the interviewees who knew about RMRM. ** indicates that these percentages are among the interviewees who had seen the sign. *** indicates that these percentages are among the interviewees who had read the sign. NA indicates that n was 0.

Segment of Interviewees	Knew About						Read Sign**	Learned From Sign***	Liked Sign
	Freshwater Mussels	Invasive Freshwater Mussels	Native Freshwater Mussels	RMRM	Sign	RMRM From Sign*			
Overall	82.8 % (n = 145)	68.3 % (n = 145)	42.8 % (n = 145)	17.2 % (n = 145)	33.1 % (n = 145)	38.7 % (n = 31)	68.8 % (n = 48)	81.1 % (n = 33)	85.3 % (n = 34)
Visitors	61.4 % (n = 44)	47.7 % (n = 44)	27.3 % (n = 44)	6.8 % (n = 44)	20.5 % (n = 44)	33.3 % (n = 3)	33.3 % (n = 9)	100.0 % (n = 3)	100.0 % (n = 4)
Locals	92.1 % (n = 101)	77.2 % (n = 101)	49.5 % (n = 101)	21.8 % (n = 101)	38.6 % (n = 101)	50.0 % (n = 22)	76.9 % (n = 39)	80.0 % (n = 30)	83.3 % (n = 30)
Infrequent Users	75.8 % (n = 91)	60.4 % (n = 91)	34.1 % (n = 91)	8.8 % (n = 91)	22.0 % (n = 91)	50.0 % (n = 8)	45.0 % (n = 20)	88.9 % (n = 9)	90 % (n = 10)
Frequent Users	94.3 % (n = 35)	77.1 % (n = 35)	60.0 % (n = 35)	28.6 % (n = 35)	42.9 % (n = 35)	35.7 % (n = 14)	73.3 % (n = 15)	100.0 % (n = 11)	100.0 % (n = 11)
Very Frequent Users	94.7 % (n = 19)	89.5 % (n = 19)	52.6 % (n = 19)	36.8 % (n = 19)	68.4 % (n = 19)	42.9 % (n = 7)	84.6 % (n = 13)	72.7 % (n = 11)	72.7 % (n = 11)
Kin Beach, Vernon, Okanagan Lake	86.8 % (n = 38)	76.3 % (n = 38)	31.6 % (n = 38)	10.5 % (n = 38)	23.7 % (n = 38)	0.0 % (n = 4)	55.6 % (n = 9)	80.0 % (n = 5)	80.0 % (n =
Peach Orchard Beach, Summerland, Okanagan Lake	79.4 % (n = 34)	73.5 % (n = 34)	61.8 % (n = 34)	29.4 % (n = 34)	50.0 % (n = 34)	80.0 % (n = 10)	82.4 % (n = 17)	78.6 % (n = 14)	85.7 % (n = 14)
Kinsmen Park, Summerland, Okanagan Lake	66.7 % (n = 6)	50.0 % (n = 6)	0.0 % (n = 6)	0.0 % (n = 6)	66.7 % (n = 6)	NA	25.0 % (n = 4)	100.0 % (n = 1)	100.0 % (n = 1)
Three Mile Beach, Penticton, Okanagan Lake	80.6 % (n = 36)	52.8 % (n = 36)	36.1 % (n = 36)	8.3 % (n = 36)	16.7 % (n = 36)	33.3 % (n = 3)	66.7 % (n = 6)	50.0 % (n = 4)	50.0 % (n = 4)
Vaseux Lake Campsite, Oliver, Vaseux Lake	80.0 % (n = 15)	73.3 % (n = 15)	73.3 % (n = 15)	26.7 % (n = 15)	33.3 % (n = 15)	0.0 % (n = 4)	40.0 % (n = 5)	100.0 % (n = 2)	100.0 % (n = 2)
Oliver Skate Park, Oliver, Okanagan River	93.8 % (n = 16)	75.0 % (n = 16)	31.3 % (n = 16)	25.0 % (n = 16)	43.4 % (n = 16)	75.0 % (n = 4)	100.0 % (n = 7)	100.0 % (n = 7)	100.0 % (n = 7)

Appendix D: Details on laboratory setup and procedures

Methods

Description of laboratory setup

The fish were housed in a temporary laboratory at the University of British Columbia's Okanagan Campus. All fish were housed in a recirculating system, containing a header (supply) tank (1), aerators, UV-filters, fish holding tanks (2), biological filters (3), a sump (collection tank) (4), pump, and chiller (see Figures 7 and 8). Water for the system was collected from Okanagan Lake, filtered through 40 µm filters, and stored in ca. 100 L storage tanks with aerators, a chiller, and a UV-filtration system. Water in the main system was replaced with water from the storage system, based on measurements of water quality parameters (see the 'Procedures' section below). Infections took place in separate 10 L tanks, which were aerated. Water for these tanks was supplied from the storage system.

1. The header tank contained approximately 60 L of water (see Figure 9). In it, the water was aerated and a separate pump re-circulated water from the header through an UV-filter. From the header, the water flowed through clear vinyl tubing to the fish holding tanks. The flow could be regulated by using stop cocks. In addition, there was a hard plastic irrigation pipe that let excess water overflow into the sump.

2. The fish holding tanks contained approximately 30 L of water (see Figures 8, 10, and 11). The lids were covered with a screen to prevent the fish from jumping out of the bins. In addition, a raised screen was placed on the bottom of the tanks to prevent the fish from eating any juvenile Rocky Mountain ridged mussels (RMRM; *Gonidea angulata*, Lea 1839) that metamorphosed and dropped off the fish. Rocks and plastic plants were used as environmental enrichment in the tanks. From the fish holding tanks, the water flowed through clear vinyl tubing, via small filtration tanks, to the biological filters. The small filtration tanks were intended for filtering out RMRM glochidia. However, due to problems with clogging of the filters and flooding, the filters were removed from the tanks and this allowed the water to flow freely through them.

3. The biological filters were made out of 20 L buckets (see Figure 9). Each filter filtered water from half the fish holding tanks. They contained layers of materials. The first layer was a perforated disk,

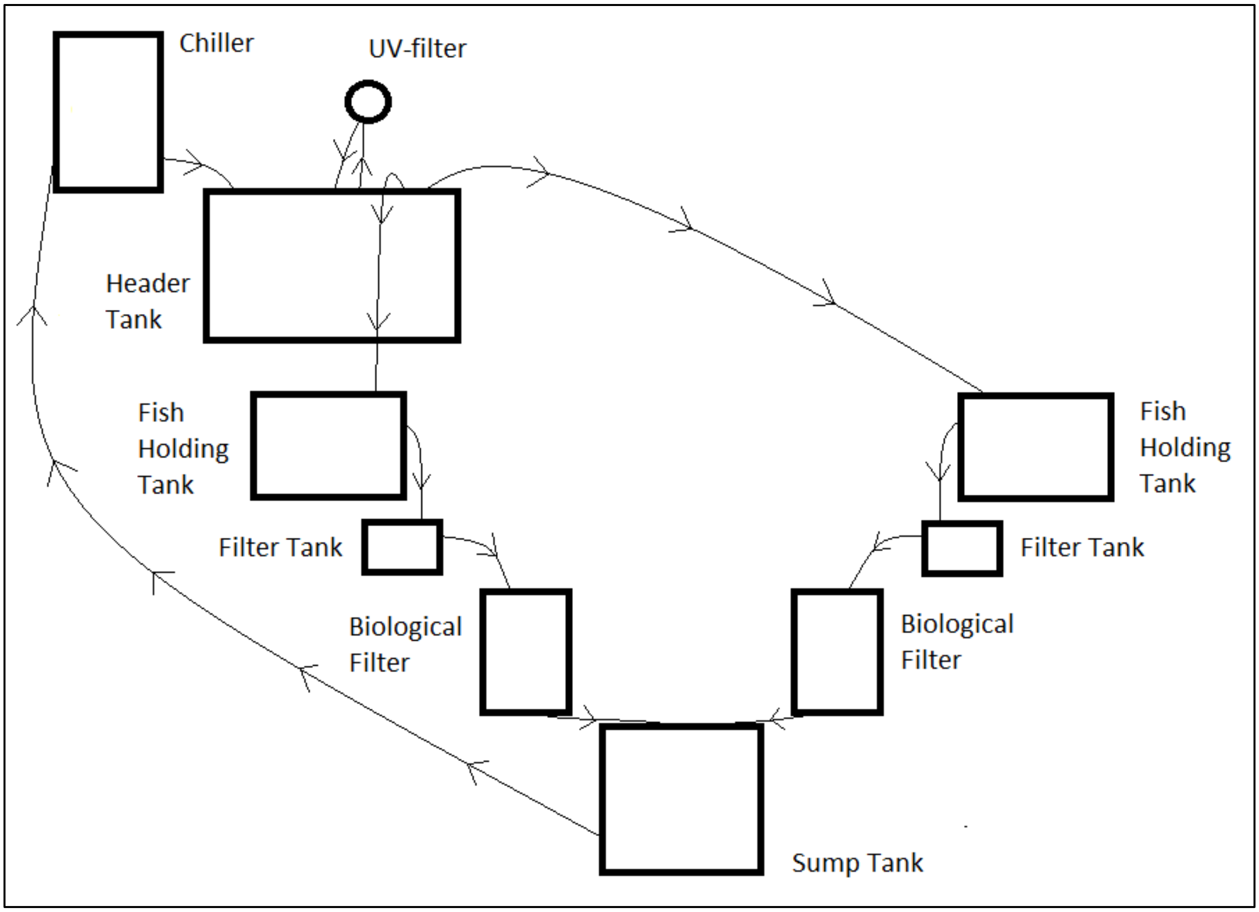

Figure 7 Overview of laboratory setup 1. The figure shows a schematic overview of the laboratory setup. The arrows show the direction of flow. Note that for the re-circulation system to work, it is important that all parts of the system maintain the height above the ground compared to one another. Also, note that I abandoned the use of the filters in the filter tanks, due to problems with clogging and overflow.

which distributed the water over the entire surface of the filter. The subsequent layers contained coarse filtering, phosphorous-absorbing, and nitrogen-absorbing materials. The final layer in the biological filter was made up filter media, which provided a growing surface for ammonia decomposing bacteria. From the biological filters, the water flowed through hard plastic irrigation pipes to the sump.

4. The sump had a capacity of approximately 200 L (see Figure 9). It contained an aerator and a pump. From the sump, the water was pumped back to the header, via the chiller. The chiller maintained the water temperature at 17 °C. The water flowed through hard plastic irrigation pipes.

Figure 8 Overview of laboratory setup 2. The photo gives on overview of the laboratory setup during construction. It shows the header tank (upper left), fish holding tanks (larger) with filter tanks (smaller), one of the biological filters (white bucket), and the tubing connecting the various parts. At this point in time, the sump, chiller, and UV-filtration system was not installed. Note that the filters (white rings) were removed from the filter tanks, due to problems with clogging and flooding. (Photo: Ian Walker)

Procedures

In the laboratory, each species of fish was housed separately and only ten specimens of each fish were maintained in a fish holding tank. Once the fish were brought to the laboratory, the transport bags were placed in the holding tanks for 30 minutes to acclimatize the fish to the laboratory water temperature, while continuing to aerate the holding bags. After acclimatization, the fish were released into the holding tank.

During pre-experimental holding of the fish, a variety of routine observations and activities were undertaken on a daily basis. In the morning the fish were fed *ad libitum* with *Mysis* shrimp and/or blood worms depending on the preference of the fish species in question. While the fish where eating, these water quality parameters were tested: Oxygen levels, temperature, pH, ammonia, nitrites, nitrates,

Figure 9 Overview of laboratory setup 3. The photo shows a partial overview of the laboratory setup. It shows the header tank (blue tank at upper left), fish holding tanks (larger), filter tanks (smaller), the two biological filters (two white buckets), the sump (white cooler at lower center), and chiller (white box at upper left, in the background), and the tubing connecting the various parts. Note the large overflow pipe returning excess water from the header to the sump. Also, note that the filters (white rings) were removed from the filter tanks, due to problems with clogging and flooding. (Photo: Melissa Mageroy)

general hardness, and alkaline hardness. Subsequently, any excess food was removed from the tanks through siphoning. If water parameters were within the recommended levels, only the water lost through siphoning of the food was replaced. If water parameters were outside of the recommended levels, sufficient water was removed and replaced from the system to bring the levels back within recommended ranges. All water added came from the storage tanks. In addition, the fish were inspected daily with respect to whether they ate, general body condition, and signs of disease. If certain fish did not eat, showed reduced body condition, or signs of disease, they were euthanized using MS-222.

At the start of the experimental holding of the fish, all fish in one holding tank were transferred using dip nets to 10 L infection tanks. These tanks contained water from the storage tanks, chilled to the same temperature as the water in the re-circulating system. In addition, the tanks contained RMRM glochidia. The water was aerated to reduce the stress to the fish and to suspend the glochidia, to make

Figure 10 Fish holding tanks 1. The photo shows the screened lids of the holding tanks and the stop cocks regulating flow into the tanks. (Photo: Ian Walker)

sure that all species of fish where exposed to the same infection pressure. After 15 minutes, the fish were transferred back to the holding tank.

During the initial stage of the experimental holding of the fish, the routines were identical to the routines maintained during the pre-experimental holding of the fish. However, five days after infection changes were made to the routines to allow for the detection of any metamorphosed juvenile RMRM that may have dropped of the fish. Every morning the contents of the bottom of the holding tanks where siphoned through 70 µm filters. The materials collected in the filters were washed into counting chambers and the chambers were inspected, under 40x magnification, for any juvenile mussels. Feeding took place after the tanks had been siphoned for glochidia, and the tanks were subsequently re-siphoned to remove any excess food. Food was only given every other day, to minimize the siphoning and potential loss of juvenile mussels through this process. This routine was maintained until fifteen days after infection. At this point the experiment was terminated and any remaining fish were

Figure 11 Fish holding tanks 2. The photo shows the fish holding tanks (larger) and filter tanks (smaller). Note that the filters (white rings) were removed from the filter tanks, due to problems with clogging and flooding. (Photo: Melissa Mageroy)

euthanized, since the developmental time of RMRM glochidia is known to be ten to eleven days (O'Brien *et al.* 2013).