PROPOSED

Species at Risk Act
Management Plan Series

Management Plan for the Rocky Mountain Ridged Mussel (*Gonidea angulata*) in British Columbia

Rocky Mountain Ridged Mussel

2011

Fisheries and Oceans Canada
Pêches et Océans Canada
Canada

About the *Species at Risk Act* Management Plan Series

What is the *Species at Risk Act* (SARA)?

SARA is the Act developed by the federal government as a key contribution to the common national effort to protect and conserve species at risk in Canada. SARA came into force in 2003, and one of its purposes is "*to manage species of special concern to prevent them from becoming endangered or threatened*."

What is a species of special concern?

Under SARA, a species of special concern is a wildlife species that could become threatened or endangered because of a combination of biological characteristics and identified threats. Species of special concern are included in the SARA List of Wildlife Species at Risk.

What is a management plan?

Under SARA, a management plan is an action-oriented planning document that identifies the conservation activities and land use measures needed to ensure, at a minimum, that a species of special concern does not become threatened or endangered. For many species, the ultimate aim of the management plan will be to alleviate human threats and remove the species from the List of Wildlife Species at Risk. The plan sets goals and objectives, identifies threats, and indicates the main areas of activities to be undertaken to address those threats.

Management plan development is mandated under Sections 65–72 of SARA (http://www.sararegistry.gc.ca/approach/act/default_e.cfm).

A management plan has to be developed within three years after the species is added to the List of Wildlife Species at Risk. Five years is allowed for those species that were initially listed when SARA came into force.

What's next?

Directions set in the management plan will enable jurisdictions, communities, land users, and conservationists to implement conservation activities that will have preventative or restorative benefits. Cost-effective measures to prevent the species from becoming further at risk should not be postponed for lack of full scientific certainty and may, in fact, result in significant cost savings in the future.

The series

This series presents the management plans prepared or adopted by the federal government under SARA. New documents will be added regularly as species get listed and as plans are updated.

To learn more

To learn more about the *Species at Risk Act* and conservation initiatives, please consult the SARA Public Registry (http://www.sararegistry.gc.ca/).

Management Plan for the Rocky Mountain Ridged Mussel (*Gonidea angulata*) in British Columbia [PROPOSED]

March 2011

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Additional copies:

Additional copies can be downloaded from the SARA Public Registry (http://www.sararegistry.gc.ca/).

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PREFACE

The Rocky Mountain Ridged Mussel is a freshwater mollusc and was listed as a species of special concern under the *Species at Risk Act* (SARA), in July 2005. SARA, (Section 65), requires the competent minister to prepare management plans for species listed as special concern. Fisheries and Oceans Canada (DFO) Pacific Region co-led the development of this management plan with the British Columbia Ministry of Environment (B.C. MoE). This document meets SARA requirements in terms of content and process (SARA Sections 65-68).

Success in the conservation of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this plan and will not be achieved by DFO or any other party alone. This plan provides advice to jurisdictions and organizations that may be involved or wish to become involved in activities to conserve this species. In the spirit of the Accord for the Protection of Species at Risk, the Minister of Fisheries and Oceans invites all responsible jurisdictions and Canadians to join DFO in supporting and implementing this plan for the benefit of the Rocky Mountain Ridged Mussel and Canadian society as a whole. The Minister will report on progress within five years.

RESPONSIBLE JURISDICTIONS

The responsible jurisdiction for the Rocky Mountain Ridged Mussel under the *Species at Risk Act* is DFO. The Province of British Columbia co-led the development of this management plan.

AUTHORS

The Province of British Columbia and DFO have cooperated in the development of this management plan with Jennifer Heron, Sue Pollard, and Heather Stalberg, the authors of the document.

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ACKNOWLEDGMENTS

Lea Gelling (B.C. MOE) provided background information and resources for mussel surveys completed in B.C. in the past three years and reviewed the management plan. Byron Woods of the British Columbia Ministry of Environment (B.C. MoE) completed occurrence mapping for the species. B.C. MoE Penticton staff Orville Dyer, Vic Jensen, Don McKee, Jerry Mitchell, and Kristina Robbins provided information for the Okanagan region and invaluable insight into the threats analysis. Jerry Mitchell has been instrumental in coordinating boat access and completing surveys in the Okanagan region. Ted Antifeau (B.C. MoE) provided information for the Kootenay region. Sarah Davies of (DFO), Sue Pollard (B.C. MoE), Leah Westereng (B.C. MoE), Lea Gelling (B.C. MoE), Raymond Lauzier, (DFO), Lily Stanton (DFO), Jennifer Heron (B.C. MoE) and Leah Ramsay (B.C. MoE) have jointly completed surveys throughout the Kootenay, Columbia and Okanagan River watersheds.

STRATEGIC ENVIRONMENTAL ASSESSMENT

A strategic environmental assessment (SEA) is conducted on all SARA recovery planning documents, in accordance with the Cabinet Directive on the Environmental Assessment of Policy, Plan and Program Proposals. The purpose of an SEA is to incorporate environmental considerations into the development of public policies, plans, and program proposals to support environmentally-sound decision making.

Management planning is intended to benefit species at risk and biodiversity in general. However, it is recognized that strategies may also inadvertently lead to environmental effects beyond the intended benefits. The recovery planning process based on national guidelines directly incorporates consideration of all environmental effects, with a particular focus on possible impacts on non-target species or habitats. The results of the SEA are incorporated directly in the management plan itself, but are also summarized below.

This management plan will clearly benefit the environment by promoting the management of the Rocky Mountain Ridged Mussel. The potential for the plan to inadvertently lead to adverse effects on other species was considered. The SEA concluded that this plan will clearly benefit the environment and will not entail any significant adverse effects. The reader should refer to the following sections of the document in particular: Habitat and biological needs; Ecological role; Limiting factors; Actions; and the Implementation Table.

EXECUTIVE SUMMARY

The Rocky Mountain Ridged Mussel is a freshwater mollusc and was listed as a species of special concern under the *Species at Risk Act* (SARA), in July 2005. This large freshwater bivalve has a trapezoidal shell. The most distinctive feature of the shell is a prominent posterior ridge running almost parallel with the anterior margin, from the umbo to the angular basal posterior margin of each valve. The posterior length of the shell exceeds the anterior length of the shell.

The life cycle of the Rocky Mountain Ridged Mussel is complex and poorly understood. After fertilization, the female incubates eggs within her shell; the eggs hatch into microscopic larvae (called glochidia). Planktonic glochidia are released from the female mussel and must attach to the gills of a suitable host fish (species unknown) within a few days of release. After this parasitic stage, the glochidia develop into a benthic free-living juvenile and drop off the host fish, where they settle into substrate and grow into an adult mussel. Adult mussels will live within suitable substrate in the littoral zone, siphoning water and growing in size. It is unknown to what water depths mussels live. The maximum age or age of maturity of adult mussels is also unknown.

In Canada, the Rocky Mountain Ridged Mussel is known to occur in British Columbia in the Okanagan River watershed, one historic occurrence from the ‘Kootenays’ (location unknown) collected in the early 1900’s and one historic occurrence labelled ‘Vancouver Island’ (location unknown).

Occurrence records from various sources yield eleven sites where live specimens have been found within the Okanagan River watershed (one location). It is difficult to define a location (as defined by the Committee on the Status of Endangered Wildlife in Canada) for the Rocky Mountain Ridged Mussel due to the lack of information on the dispersal of the species at all life stages.

The current range of the Rocky Mountain Ridged Mussel includes the Okanagan River watershed, from the northernmost record in Vernon to the southernmost record of a shell found in the Osoyoos area. The range extent will be expanded if occurrences are found in the Kootenay or Columbia River watersheds, or the historic record from Vancouver Island is confirmed.

Population information on the Rocky Mountain Ridged Mussel is unknown and densities likely vary depending on habitat suitability and quality, with lower quality habitat supporting lower mussel densities. Most records are from 1 – 10 individuals within a survey area. However, there are three sites in the Okanagan River watershed with colonies > 100 individuals.

Threats to the Rocky Mountain Ridged Mussel are not well understood. Potential threats include: 1) foreshore/riparian development; 2) historic riverbed channelization; 3) hydrograph modification and regulation; 4) aquatic introduced species; 5) host species availability; 6) watershed land-use related pollution; 7) disturbance or direct harm; and 8) climate change.

The management goal for the Rocky Mountain Ridged Mussel is to *maintain viable, self-sustaining, ecologically functioning and broadly distributed populations within suitable habitats in its current distribution/range in B.C.*

The management objectives for the Rocky Mountain Ridged Mussel are: 1) By 2015, address knowledge gaps about the life history, provincial range and threats to the Rocky Mountain Ridged Mussel; 2) By 2015 inventory 75% of potential littoral habitat within the Okanagan River watershed, with standardized protocol for habitat and threat information collected at each site searched; 3) By 2015, demonstrate an increased number of stewardship activities initiated and completed for land managers and public users of habitats occupied by the Rocky Mountain Ridged Mussel; and 4) As research and inventory results on Rocky Mountain Ridged Mussel become available, incorporate into land-use planning to inform future threat mitigation and land use protection.

The approach to implementing new actions is to focus on addressing the uncertainty related to the Rocky Mountain Ridged Mussel e.g. life history, limiting factors and threats, through research and assessment thereby strengthening the foundation for future management actions.

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1. BACKGROUND

The Rocky Mountain Ridged Mussel (*Gonidea angulata*) is a freshwater bivalve in the subfamily Ambleminae, which includes a number of thick shelled and commercially important mussel species. The Rocky Mountain Ridged Mussel is considered taxonomically isolated and is the only known living representative of the *Gonidea* genus in North America (Graf, 2002). The genus *Gonidea* has an extensive fossil record in western North America (for further details refer to COSEWIC, 2003) and the taxonomy around the genus is problematic (COSEWIC, 2003), owing to this extensive fossil record. The closest living species in this genus is thought to be from Korea, although research has yet to confirm a taxonomic relationship (COSEWIC, 2003).

The Rocky Mountain Ridged Mussel is also known as Western Ridged Mussel and Western Ridgemussel (COSEWIC, 2003). Additional scientific names include *Anodonta feminalis* Gould,1850; *Anodonta randalli* Trask, 1855; *Anodonta biangulata* Sowerby, 1869; *Anodonta angulata* var. *subangulata* Hemphill, 1891; *Gonidea angulata* var. *haroldiana* Dall, 1908 (Taylor, 1977 as read in COSEWIC, 2003).

1.1 Species Assessment Information from the Committee on Status of Endangered Wildlife in Canada (COSEWIC)

Date of Assessment: November 2003

Common Name (population): Rocky Mountain Ridged Mussel

Scientific Name: *Gonidea angulata* Lea 1839

COSEWIC Status: Special Concern

Reason for Designation: The distribution of this species is limited to southern British Columbia in the Okanagan and Kootenay River systems. This species has likely been impacted by the damming of the Kootenay, Columbia and Okanagan Rivers and the channelization of the Okanagan River and resulted in loss or alteration of the mussel's habitat quality and extent.

Canadian Occurrence: British Columbia

COSEWIC Status History: Designated Special Concern in November 2003. Assessment based on a new status report.

1.2 Description of the Species

The Rocky Mountain Ridged Mussel is a large freshwater bivalve (shell ≤ 125mm long; ≤ 65 mm high; 40 mm wide; shell wall ≤ 5 mm thick). The trapezoidal shell is variable in form; the distinguishing feature of the shell being a prominent posterior ridge running almost parallel with the anterior margin, from the umbo to the angular basal posterior margin of each valve (Figure 1 and Figure 2). The posterior length of the shell exceeds the anterior length of the shell.

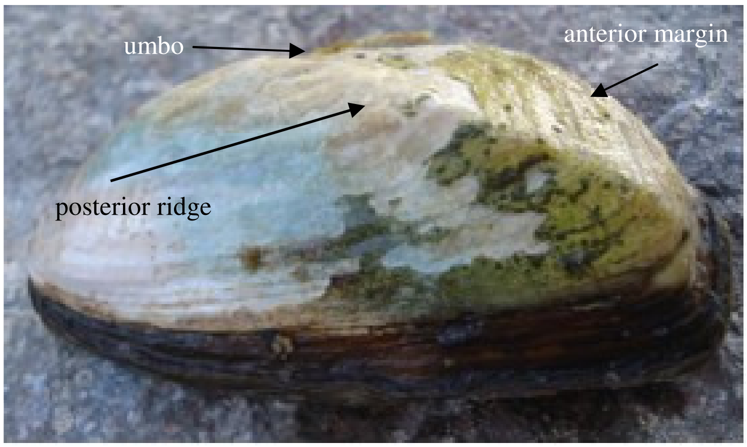

Figure 1: Adult Rocky Mountain Ridged Mussel found below the first weir in the Okanagan River south of Oliver, B.C, July, 2007. Note the distinctive prominent angular ridge running almost parallel with the anterior margin of the shell. The posterior length of the shell exceeds the anterior length. Photo J. Heron.

Figure 2: Small (potentially young) Rocky Mountain Ridged Mussel found July 2007 near Summerland, B.C. within the lakeshore of a recreational beach along Okanagan Lake. Photo J. Heron.

Rocky Mountain Ridged Mussel shells have numerous prominent and slightly elevated concentric growth lines, or growth rests, radiating from the umbo region (Figure 2). The periostracum is yellowish brown to blackish brown. The nacre (Figure 3) is usually white or salmon coloured at the anterior and thickest umbo region of the shell, gradually darkening to a pale blue along the posterior outer margins of the shell (Figure 4).

Figure 3: Adult Rocky Mountain Ridged Mussel shell found at Dog Beach, Summerland, B.C. June 28, 2007. Note nacre colouration change from white at the hinge to salmon to bluish at the posterior margin of the shell. Photo J. Heron.

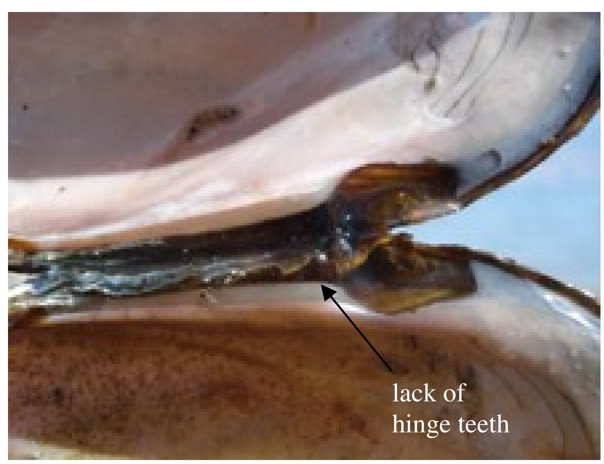

Figure 4: Inside of Rocky Mountain Ridged Mussel shell, showing the (lack of) hinged teeth and pseudocardinal teeth. Photo J. Heron.

To prevent lateral slipping between shell halves, bivalves have a series of teeth or ridges with opposing sockets and grooves, located beneath the hinge ligament and on the hinge line of the shell (Ruppert *et al.,* 2004). The hinge teeth of the Rocky Mountain Ridged Mussel are described as indistinct, irregular and poorly developed (Figure 4); the pseudocardinal teeth are laterally expanded, low and compressed (one in the right valve and none or one in the left valve); and the lateral teeth are absent (COSEWIC, 2003).

Three species of freshwater mussels overlap with the Canadian range; these species include California Floater (*Anodonta californiensis/nuttalliana*), which lacks the distinct posterior ridge and has a wing-type shell (Chong, 2008), Western Floater (*Anodonta kennerleyi/oregonensis*) which has a smooth and thin shell with concentric growth rings that are not prominently ridged (Chong, 2008), and Western Pearlshell, (*Margaritifera falcata*) which has no prominent posterior ridge, a larger and more developed hinge, larger more prominent pseudocardinal teeth, a purple nacre, and a dark coloured, elongated shell (See Appendix 1 for photographs of these species).

Many life history characteristics of the Rocky Mountain Ridged Mussel in southern British Columbia remain unknown, and in need of further study. The Rocky Mountain Ridged Mussel likely follows the general life cycle pattern of other similar Unionid/Ambleminae species (Ruppert *et al.*, 2004). Reproduction is thought to be annual with a short breeding season. Spawning occurs in the spring (tachytictic life cycle) and glochidia are released sometime during the summer months. Evidence to support the tachytictic reproductive strategy in the Rocky Mountain Ridged Mussel is threefold: 1) the observation of gravid females from April through June but not in August through October (Spring Rivers, 2007). On June 28, 2007, conglutinates were observed being released from Rocky Mountain Ridged Mussel at Kinsmen Regional Park (Summerland Dog Beach), Summerland (Figure 6 and Figure 7 and see Figure 5 Life Cycle); 2) tachytictic strategy is common within other species of subfamily Ableminae; and 3) the increase in spring seasonal flow of many waterways where the species has been found (COSEWIC, 2003) likely contributes to the dispersal of sperm following its release by male mussels (Figure 5, Life Cycle). Seasonal water flow and spring runoff in B.C. may allow for increased dispersal of the glochidial life stage, ensures cool water during glochidia release, and may act as an environmental trigger that initiates reproduction. Other freshwater mussels spawn in the summer, with glochidia overwintering in the female mussels, and released the following spring (bradytictic life cycle). Further explanation of possible (although unlikely) life cycle patterns is described in Dillon (2000), Bauer and Wächtler (2001), and McMahon and Bogan (2001) (as read in COSEWIC, 2003).

The limited information on the behaviour of the Rocky Mountain Ridged Mussel is based on field observations (Appendix 2). At Okanagan Lake, Kinsmen Regional Park, Summerland, where greater than 100 mussels were observed within the same site on the same day (July 13, 2006) (Appendix 2), specimens were positioned ranging from a few centimetres apart to a few metres apart, and from almost completely buried in the substrate to lying flat on the substrate surface. The highest density of mussels was observed in a band parallel to the shoreline, approximately 15 metres from shore and at a 1.2 metre depth (Moore and Machial, 2007). Mussel surveys were only completed within the littoral zone, thus it is unknown if the colony extended past this zone into deeper depths.

Specific information on the life cycle of the Rocky Mountain Ridged Mussel in B.C. is limited. Biological information described below is from the COSEWIC status report (2003), research on the Rocky Mountain Ridged Mussel in California (Spring Rivers, 2007) and general information about freshwater mussels written in Ruppert *et al.* (2004). The basic life cycle is described in six stages (Figure 5). Environmental and water temperatures determine the survival, growth and reproduction of freshwater mussels (discussed further in limiting factors).

1.2.1. Life Cycle of the Rocky Mountain Ridged Mussel

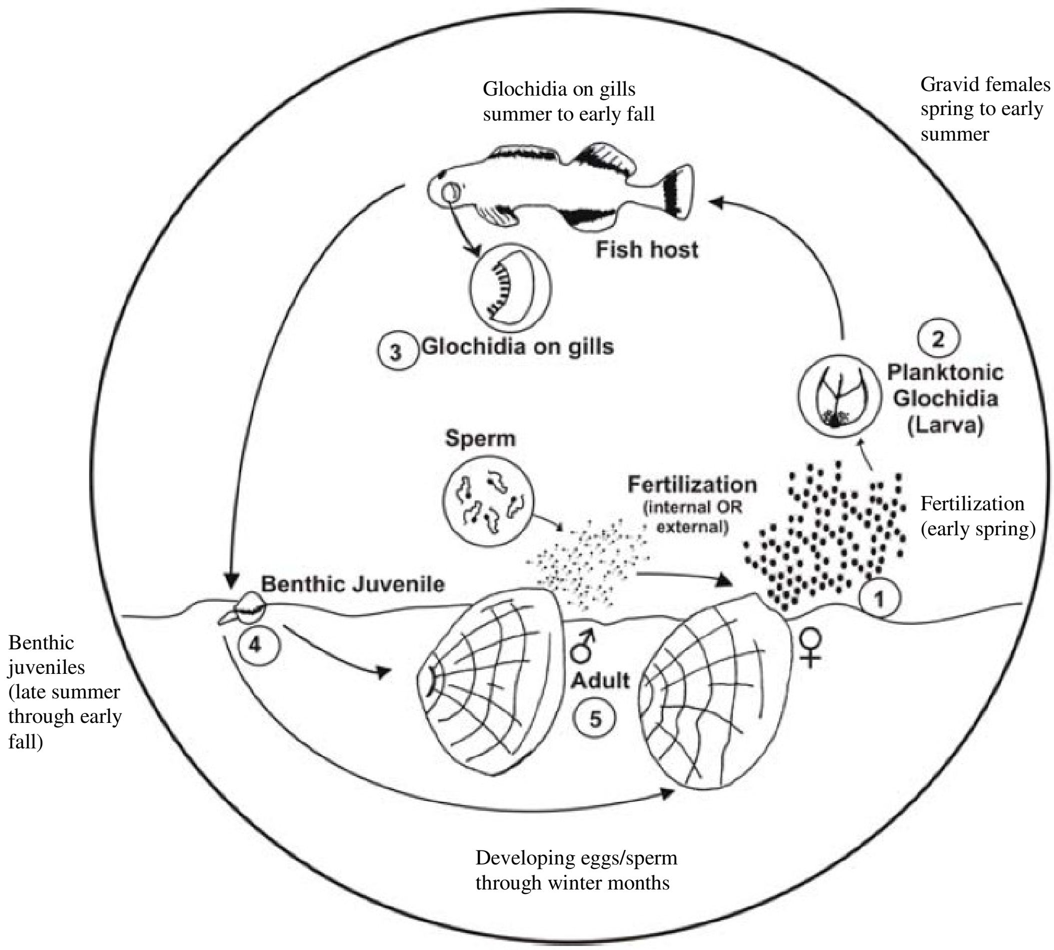

Figure 5: Generalized diagram of the life cycle of the Rocky Mountain Ridged Mussel. Life stage (1) and (2) late spring through early summer gravid females release larvae and larvae find a glochidia host fish. Life stage (3) summer through early fall glochidia grow within host fish and drops from the gills. Life stage (4) benthic juveniles free float and settle in the substrate during fall. Life stage (5) juvenile mussel growth continues, although it is unknown at what age the species is able to reproduce. Diagram source COSEWIC (2003) (Figure provided by Terry Frest, 2008).

- ***Unfertilized eggs*** (Figure 5, life stage 1) develop in the gills of female mussels. Fertilization is likely internal. Mussel males (from various species) typically release sperm into the water column, which passively drifts with water currents. As the female mussel siphons water through her gills she also siphons in sperm, which then fertilizes her eggs. Note this has not been studied in the Rocky Mountain Ridged Mussel. It is unknown how many eggs a female Rocky Mountain Ridged Mussel is able to produce yearly (on average), nor what age the mussel will begin to produce eggs/sperm. The species is not likely self-fertilizing. Reproduction may be triggered by increased day length, or seasonal changes to water temperatures, although this information is not known.

- ***Glochidia development*** (Figure 5 life stage 1) begins once eggs are fertilized. Studies in California show gravid females from late April through mid July (Spring Rivers, 2007). Eggs hatch into microscopic larvae called glochidia, which develop in the gills of female mussels. Glochidia development within the female mussel likely spans 1 – 4 months.

- ***Planktonic glochidia*** (Figure 5 life stage 2) are released from the female mussel, float within the water column, find a suitable host fish within a few days of release and embed in the gills of this host fish (host fish are discussed below in 3) *parasitic or commensalistic glochidia* life stage). Some mussel species have specialized structures, mucilaginous tubes called conglutinates, that increase the chances of their glochidia finding a suitable host fish (Figure 6 and Figure 7). Conglutinates allow larvae to readily attach to the gills of the host fish. There are many examples of elaborate methods unionoids use to attract host fish to glochidia (Strayer, 2008) although information on conglutinate attractants has not been studied in the Rocky Mountain Ridged Mussel. The COSEWIC status report (2003) states the Rocky Mountain Ridged Mussel likely does not exhibit this behaviour, however it appears this information was reported in error. On June 28, 2007, one Rocky Mountain Ridged Mussel was observed releasing conglutinates at Kinsmen Regional Park (Summerland Dog Beach), Okanagan Lake (Figure 6 and Figure 7). Conglutinates were collected and identification confirmed as Rocky Mountain Ridged Mussel (Lee pers. comm. 2007). The mussel releasing conglutinates was located in approximately 1.5 metres of water within the littoral zone and semi-wedged in-between cobbles covered in silt (Figure 6 and Figure 7). The water temperature, flow and chemistry information was not collected.

  The timing of glochidia release is not known for the Rocky Mountain Ridged Mussel, although gravid females have been collected in April through July (COSEWIC, 2003) and thus females likely release glochidia in spring and early summer (April through July). Studies in Pit River, California, show Rocky Mountain Ridged Mussel glochidia presence within the water from April through July, with peak abundance in mid June (Spring Rivers, 2007). Information from other mussel species (although few species have been studied) estimate glochidia survival between 10 and 18,000 individuals per billion glochidia that survive to the 1 – 2 year stage (Jansen *et al.*, 2001 as read in COSEWIC 2003).

  Genetic studies of unionids vary widely across species (Strayer, 2008) and the dispersal factors limiting distribution and abundance of mussel populations needs further study (Strayer, 2008).

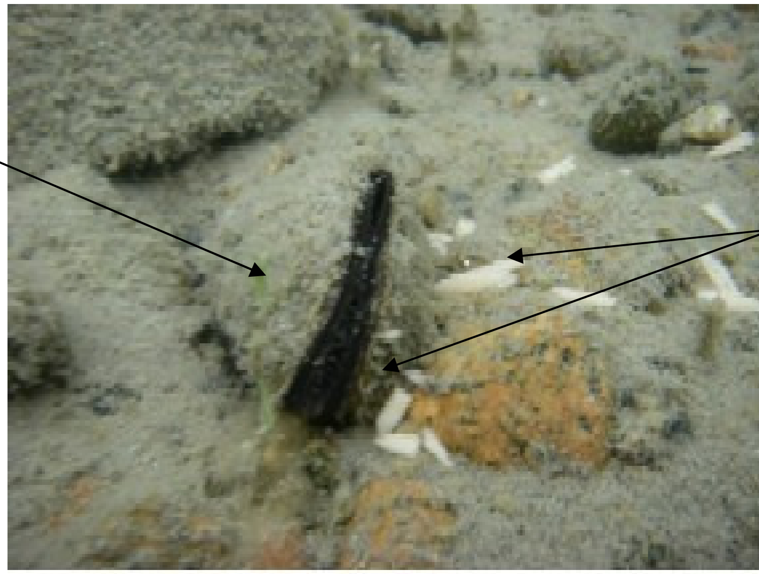

Figure 6: Rocky Mountain Ridged Mussel conglutinates, June 28, 2007 at Okanagan Lake; Summerland Dog Beach. Photo Sue Pollard.

Figure 7: Rocky Mountain Ridged Mussel conglutinates, June 28, 2007 at Okanagan Lake; Summerland Dog Beach. Photo Sue Pollard.

- ***Parasitic (or commensalistic) glochidia*** (Figure 5 life stage 3) live and grow within the gills of a living host fish from two weeks to four months (possibly one to six weeks) (COSEWIC, 2003). Numerous glochidia can live within the same host fish and the attachment of glochidia is usually not detrimental to the host fish (Cunjak and McGladdery, 1991). Research on the Rocky Mountain Ridged Mussel in California observed glochidia on host fish from late March through mid July (Spring Rivers, 2007).

  Host fish are the primary dispersal mechanism for mussels, which are predominantly sedentary for their adult lives. Confirming a host fish is difficult for any mussel species and research on the host fish for the Rocky Mountain Ridged Mussel is limited. Research findings on host fish for the Rocky Mountain Ridged Mussel in California are: 1) native Tule perch (*Hysterocarpus traski*), which is the only viviparous species native to

California; 2) native Pit sculpin (*Cottus pitensis*) and 3) native Hardhead *(Mylopharodon conocephalus*) (Spring Rivers, 2007). Spring Rivers (2007) research found more juvenile mussels transformed on Pit sculpin than Hardhead or Tule perch and suggest this fish may be the most important host for the Rocky Mountain Ridged Mussel within this part of the species range.

In California, unconfirmed host fish for the Rocky Mountain Ridged Mussel glochidia include Torrent sculpin (*Cottus rhotheus*), Rainbow trout (*Oncorhynchus mykiss*) and non-indigenous Black crappie (*Pomoxis nigromaculatus*) (Spring Rivers, 2007). Unconfirmed host fish are fish with encysted glochidia on their gills, yet it is unconfirmed if mussels live successfully after glochidia drop off the gills of the host fish. These three fish species live within the range of the Rocky Mountain Ridged Mussel (according to McPhail, 2007). Torrent sculpin are found throughout the Okanagan, Similkameen and Kettle River systems, in areas below fish barriers and dams (McPhail, 2007). Rainbow trout are widely distributed throughout the Okanagan and Columbia basins (McPhail, 2007). Black crappie are known from Osoyoos Lake (Okanagan basin and from the lower Pen d'Oreille near the confluence with the Columbia River south of Trail) (McPhail, 2007).

- ***Benthic free-living juvenile*** (Figure 5 life stage 4) mussels drop off the host fish and settle into substrate to grow to adult form. Lab studies in California show glochidia drop off host fish gills sometime between June and late July (Spring Rivers, 2007). The timing of this life stage in B.C. is unclear.

- ***Adult mussels*** (Figure 5 life stage 5) live within suitable substrate (see habitat information for substrate description) within the littoral zone (although it is unknown at what depth mussels will live), siphoning water and growing in size. It is unknown at what age Rocky Mountain Ridged Mussels will reproduce, how fast the species grows, or the potential numbers of progeny an individual adult produces.

  The ridges on the surface of the Rocky Mountain Ridged Mussel shells have distinct black lines that can be counted to estimate age, similar to how one would count the growth rings on a tree. These rings represent winter low-growth periods but can be inconsistent. This method has variable accuracy, becoming less accurate as mussels age and growth rates decline (Ruppert *et al*., 2004). The maximum age at maturity of the Rocky Mountain Ridged Mussel is unknown, although based on preliminary estimates from growth ring counts the species may live 20 – 30 years (COSEWIC, 2003).

1.3 Populations and Distribution

The global range of the Rocky Mountain Ridged Mussel is entirely within western North America from southern California north to southern B.C., eastward through southern Idaho and northern Nevada (Taylor, 1981) (Figure 8). Within this global range, the Rocky Mountain Ridged Mussel has a patchy distribution. The majority of occurrence records are from south of the Wisconsinan glacial margin and follow some of the major drainages throughout Washington, Oregon, Idaho and Nevada; although it is absent from most of southern California (Figure 8).

Figure 8: Global range of the Rocky Mountain Ridged Mussel, *Gonidea angulata*. Note the species has a patchy distribution throughout its global range. Map source COSEWIC (2003).

The Canadian range of the Rocky Mountain Ridged Mussel is entirely within B.C., and live specimens are confirmed only from the Okanagan River watershed (Figure 9). Although historic records indicate that Rocky Mountain Ridged Mussel's range extends into the Kootenays and Vancouver Island, the current range in B.C. is unclear as no live specimens have been observed to confirm such range extent. There is one historic record labelled 'Kootenays' (location unknown) (COSEWIC, 2003); the Kootenay system is a tributary to the Columbia River. One specimen housed at the University of Michigan Museum of Zoology is labelled 'Vancouver Island', and was likely collected in 1890 but has no specific information attached to the specimen (*Anodonta angulata* specimen #107902) (Gelling, Pollard and Ramsay, draft, 2009). It is possible the shell labelled 'Vancouver Island' was traded and/or carried along existing trade routes between the southern interior and Vancouver Island (Gelling, Pollard and Ramsay, draft, 2009). The Rocky Mountain Ridged Mussel also occurs in the Similkameen River south of the US border, within Washington State, although specimens have not been collected in this river on the Canadian side of the border. Surveys in October, 2009 did not yield records within the Similkameen and further surveys are needed. Also, the species occurs in the Columbia River south of the US border.

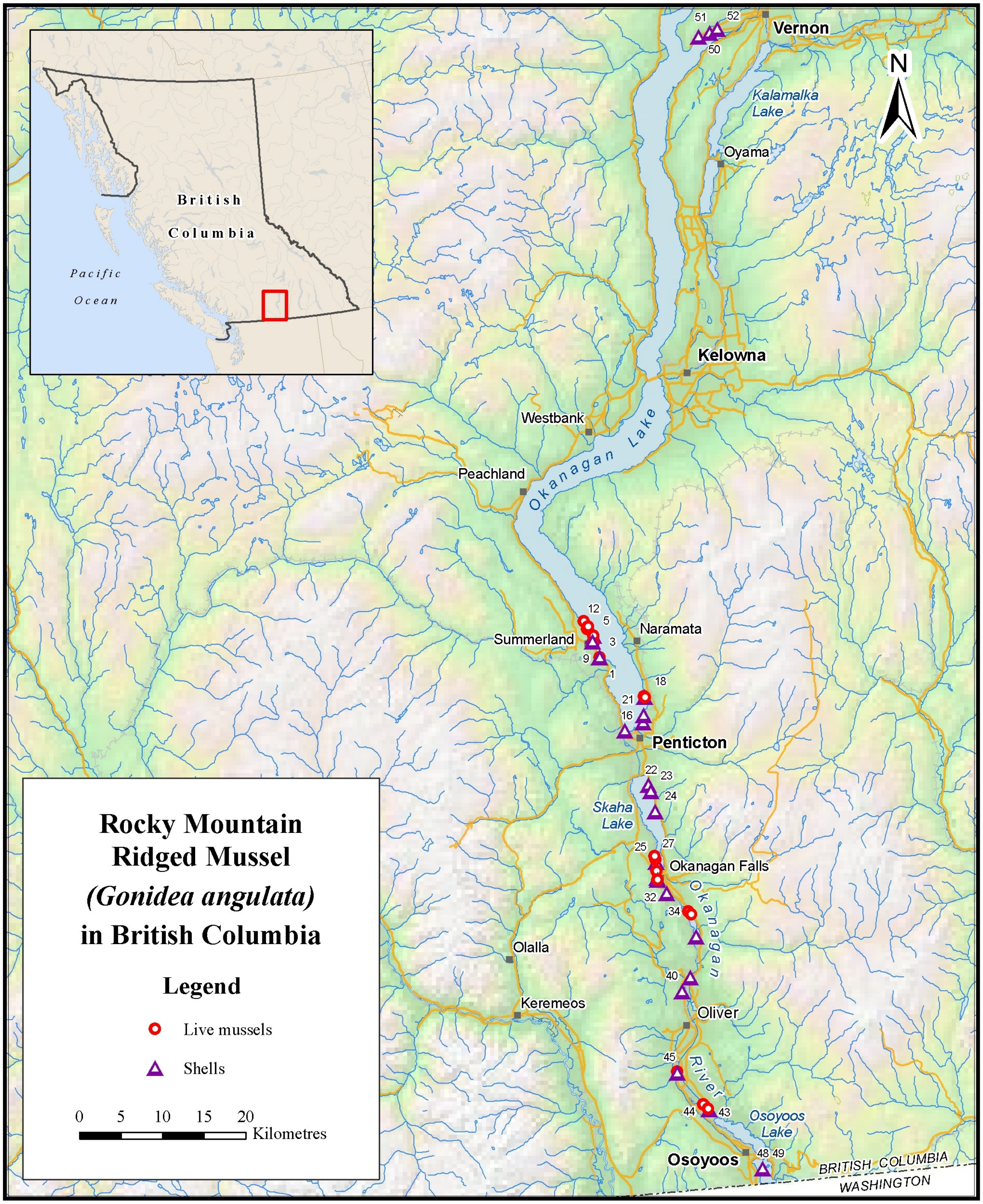

Figure 9: Canadian range of the Rocky Mountain Ridged Mussel. Source British Columbia Ministry of Environment Conservation Data Centre (updated April 2009 by Byron Woods, B.C. MoE).

Live specimens have been found at eleven sites in B.C. within the southern Okanagan River watershed (Figure 9) (B.C. Conservation Data Centre, 2009) (Appendix 2). It is difficult to define a location (as defined by COSEWIC) for the Rocky Mountain Ridged Mussel due to a lack of information on the dispersal limitations of both the sperm release and glochidia life stages, and the overall dispersal and movement ability of the adult. It is thought individual Rocky Mountain Ridged Mussels do not move far from their initial dispersal and establishment in substrate as a juvenile mussel (COSEWIC, 2003).

Population information on the Rocky Mountain Ridged Mussel is limited and densities likely vary depending on habitat suitability and quality, with lower quality habitat supporting lower mussel densities (COSEWIC, 2003). To date, surveys have been broad-brush and focused primarily on presence/absence information within a given area.

Numerous sites in south eastern B.C. have been surveyed for mussel presence in the past three years, although portions of the Shuswap, Similkameen, Columbia and Kootenay watersheds remain unsurveyed. In 2007, the B.C. MoE sponsored an invertebrate survey which included snorkelling and/or visual surveys for the Rocky Mountain Ridged Mussel with the goal to determine distribution and relative numbers in the Similkameen, Okanagan and Kootenay River watersheds. A total of 68 sites were surveyed within eleven watersheds, and the Okanagan River Watershed was the only system with confirmed occurrences of the Rocky Mountain Ridged Mussel (Moore and Machial, 2007). Field surveys in 2008 and 2009 did not find Rocky Mountain Ridged Mussels within the Kootenay, Columbia or lower Similkameen River watersheds (B.C. Conservation Data Centre, 2009).

Most records for live Rocky Mountain Ridged Mussels are for 1 – 10 individuals within a defined survey area (Appendix 2). Three sites in the Okanagan River watershed have estimates of relative numbers of live mussels: 1) Okanagan Lake, Summerland Dog Beach site, the population is estimated at greater than1000 individuals; 2) Okanagan Lake, Kinsmen Regional Park, Summerland, is estimated at greater than 100 individuals; and 3) Okanagan River (south of Skaha Lake) below the first dam is estimated at approximately 200 individuals (B.C. Conservation Data Centre, 2009). Sampling design with consistent protocol needs to be developed for future surveys.

Elsewhere within the species' range, in the western United States, Frest (unpublished data, as reported in COSEWIC 2003) observed individuals with separation distances greater than 10 metres and densities of ~1/25m^2 in the Lower Granite Reservoir, Washington; and densities of ~16/m^2 in the Okanogan River, Washington (1988 and 1991). Vannote and Minshall (1982) observed densities from 5.5 – 183/m^2 in the Salmon River Canyon, Idaho. Comparative density data are not available for B.C. sampling sites.

The Rocky Mountain Ridged Mussel is listed as globally vulnerable (G3) due to its restricted range and overall rarity throughout its known global range (NatureServe, 2009). In B.C. the species is red-listed (S1) (B.C. Conservation Data Centre, 2009).

1.4 Needs of the Rocky Mountain Ridged Mussel

The habitat, biological needs, and life history requirements for the Rocky Mountain Ridged Mussel are categorized as: 1) freshwater macro-habitat types; 2) substrate requirements; 3) glochidia host fish(es) and 4) food requirements.

1.4.1 Habitat and biological needs

Surveys completed in B.C. by the B.C. MoE and DFO from 2005 – 2009 show that the Rocky Mountain Ridged Mussel typically does not inhabit lakeshore habitat where water levels drop enough to leave the mussel exposed to the air, where substrates are periodically shifting and turbidity is high, or where there are fluctuations in oxygen and seasonal anoxia/hypoxia (B.C. Conservation Data Centre, 2009). Based on habitat information gathered during these surveys, the mussel is found in areas where substrates are stable and water quality is consistent throughout the year. It has been noted this species has a reduced tolerance to nutrient loading, substrate shift and siltation, and low flow regimes (COSEWIC, 2003). Habitat data collected at known sites in B.C. are somewhat contradictory to habitat data collected from United States (U.S.) populations, where the species appears to inhabit larger, slow-flowing river systems (Spring Rivers, 2007).

1) **Freshwater macro-habitat types**. Extant B.C. Rocky Mountain Ridged Mussel occurrences are predominantly found within lakeshore habitats, although it is uncertain if this is a habitat preference at the northernmost part of the species' range or an artefact of a once larger historic distribution (see Threats section for further discussion). Populations of the Rocky Mountain Ridged Mussels within the southern parts of its global range are generally found in larger, slow moving, constantly flowing and well-oxygenated freshwater habitats including rivers, creeks, streams, lakes and tributaries (COSEWIC, 2003). Surveys within B.C. from 2005 – 2009 (by B.C. MoE and DFO) have located the species in shallow depths (< 4 metres) within the littoral zone (although this preference may be due to access and sampling bias as surveys have not been completed at greater depths) (B.C. Conservation Data Centre, 2009). The Rocky Mountain Ridged Mussel appears to favour coldwater habitats (COSEWIC, 2003) although specific temperature information is undocumented for B.C.

2) **Substrate requirements**. In B.C. the Rocky Mountain Ridged Mussel has been found in a variety of substrates including large cobble, gravel and sandy openings, muddy sediments with sparse vegetation, cobble and gravel over sand, and areas where sediment became turbid when disturbed. All locations where live mussels have been found are within the littoral zone. Three locations in B.C. have mussel populations greater than 100 individuals, and the substrate at these locations is a mud, cobble, gravel and sand combination (mixed substrate with muddy or soft surface layer). At most locations mussels are almost completely buried with only the posterior lip of their shell exposed. Within the Okanagan River live mussels have been observed downstream of McIntyre Dam. Mussels have mostly been observed wedged between rocks and gravel. In coarser substrates, burying may reduce harm from larger substrates moving along the bottom of the waterway. Surveys in B.C. have only been conducted at depths less than three metres, thus information on substrate and depth preferences is incomplete. Studies in the U.S. have found the species at depths up to 20 metres (COSEWIC, 2003). Attempts at using

an underwater camera to survey deeper depths in B.C. were inconclusive (Lauzier pers. comm. 2009).

It is unknown if aquatic vegetation plays a role in the habitat preferences of the Rocky Mountain Ridged Mussel. Specimens have been noted within plant detritus at the mouth of the Okanagan River (COSEWIC, 2003). Live specimens have been recorded within proximity to emergent vegetation at Okanagan Lake, Summerland - Illahie Beach Recreational Vehicle Park (B.C. Conservation Data Centre, 2009). At Vaseaux Lake Provincial Park two live mussels were observed within proximity to submerged aquatic vegetation (B.C. Conservation Data Centre, 2009).

3) **Host fish**. The Rocky Mountain Ridged Mussel requires a host fish to complete its glochidia life stage. The B.C. host fish and the environmental conditions necessary for glochidia survival are unknown (for further discussion of host fish refer to section 1.2 Description of the Species).

4) **Food requirements**. Unionoid mussels feed upon suspended phytoplankton, zooplankton, bacteria, dissolved organic matter and detritus, and fungal spores (Strayer, 2008). Rocky Mountain Ridged Mussels are filter feeders, absorbing organic debris and nutrients from the water column. It is unknown what nutrients, microorganisms, or minerals are specifically needed and consumed by the Rocky Mountain Ridged Mussel. Mussels need calcium for healthy shell growth (Strayer, 2008) which they extract from the water. In general, mussel species with thin shells indicate freshwater habitat with fine sediment that, when shifted, likely does not harm mussels; a thin shell adequately protects those particular mussels. The Rocky Mountain Ridged Mussel has a thick and calcareous shell and thus would be expected to inhabit freshwater habitats that have periodically shifting substrates; the thick shell provides greater protection to the mussel.

1.4.2 Ecological role

Freshwater mussels are an integral component of the food web in aquatic ecosystems (Vaughn *et al.,* 2007). Adult mussels are filter feeders, consuming suspended organic matter and a wide range of organisms (e.g. diatoms, phytoplankton, and bacteria) from the water column (Vaughn *et al.,* 2007; Strayer 2008). Conversely, and depending on the life stage, freshwater mussels are consumed by herons, ducks, fish, raccoons, otters, muskrats and other predators. The amount of water an individual mussel siphons and filters is variable depending on the size and population at a given location. Although the overall contribution is not fully understood, mussels improve water quality through filter feeding and straining out pollutants and suspended particulates (Farris and van Hassel, 2006) at least at the microsite scale.

Mussels are commonly used as a measure of the biological integrity of a freshwater system and indicators of freshwater ecosystem health (Bertram and Stadler-Salt, 1999). Mussel shells have also been analyzed to determine current and historic levels of pollutants within water systems (Pampanin *et al.,* 2005). The decline or absence of mussels from aquatic systems can indicate chronic levels of water pollution (Farris and van Hassel, 2006).

1.4.3 Limiting factors

Limiting factors of the Rocky Mountain Ridged Mussel include the following:

1) ***Dispersal*** of the Rocky Mountain Ridged Mussel is mainly passive and primarily occurs while the parasitic glochidia larvae are attached to the gills of the host fish. Dispersal is limited during the planktonic juvenile life stage and the benthic free-living juvenile mussel stages (Figure 5). Distribution is limited by water current patterns and waterway connectivity. Movement and dispersal of post-glochidia (adult) mussels is unknown. Individuals that have been displaced may reorient and rebury themselves if conditions are appropriate. Seasonal or breeding migration has not been observed and the species does not appear to readily colonize new habitats (COSEWIC, 2003).

2) ***Freshwater habitat connectivity*** will determine the extent to which the Rocky Mountain Ridged Mussel may disperse between and within watersheds. For example, naturally created and anthropogenic barriers (such as dams and wiers), as well as patchily distributed habitats separated by large areas of undesirable habitats, will limit movement of both host fish and glochidia. This may lead to population decline if the mussels historically relied on this movement for recruitment.

3) ***Host fish*** are required for the Rocky Mountain Ridged Mussel to complete its glochidia life stage (Section 1.2). It is unknown if this is currently limiting mussel productivity in B.C. The host fish is thought to be the predominant means of a mussel's dispersal (Strayer, 2008).

4) ***Small and isolated populations*** may limit dispersal or reproductive potential of the Rocky Mountain Ridged Mussel. At some locations the species appears to be isolated, with records from 1 – 10 individuals spaced from 10 cm to 50 metres (B.C. Conservation Data Centre, 2009). Although it would seem glochidia dispersal through aquatic pathways would be effective, the maximum dispersal distance of sperm and glochidia are unknown and may limit gene flow and breeding potential. A metapopulation structure may exist and be important to the survival and persistence of the Rocky Mountain Ridged Mussel in certain watercourses. If locations are isolated, genetic diversity may be less and thus breeding success may decrease over the long term. Sessile organisms like freshwater molluscs have minimum densities at which successful reproduction is possible. If densities fall below these thresholds, reproduction is greatly compromised (Strayer, 2008). This information is unknown for the Rocky Mountain Ridged Mussel and requires population level studies.

5) ***Slow growth rates*** may limit the reproductive potential of the Rocky Mountain Ridged Mussel. The age of sexual maturity may be size limited. Mussel growth rates are closely linked to abiotic factors such as water temperature, chemistry and flow regimes (Strayer, 2008), and it is difficult to separate these factors from slow growth rates that may just be part of the species' natural history.

6) ***Food and nutrient availability*** may limit Rocky Mountain Ridged Mussel populations.

The mussel is a filter feeder and although the specific food requirements are unknown, other unionid mussels filter phytoplankton and other microorganisms, including bacteria and organic debris, from the water column (Strayer, 2008). Okanagan Lake is considered nutrient poor (Okanagan Lake Action Plan, 2008) and may limit mussel populations.

7) ***Water temperature, changes to water chemistry and flow regimes*** are all factors that determine the survival, growth and reproduction of freshwater mussels (Strayer, 2008). These factors also have the potential to affect food and nutrient levels in aquatic systems.

8) ***Available suitable substrate*** may limit the establishment of large Rocky Mountain Ridged Mussel beds. Knowledge of optimal substrate habitat in B.C. is unclear and large mussel beds in B.C. occur in habitat that is different from that described in the southern (U.S.) parts of the species' range.

1.5 Threats

The Canadian range of the Rocky Mountain Ridged Mussel coincides with an area of B.C. which is rapidly growing and changing due to urban development and human population growth. As such, development of littoral and lakeshore zones will undoubtedly continue to expand. In B.C. threats to the Rocky Mountain Ridged Mussel are predominantly habitat related, and not a result of direct exploitation of the mussel (COSEWIC, 2003).

Threats to the Rocky Mountain Ridged Mussel in order of predominance are: 1) foreshore/riparian development; 2) historic riverbed channelization; 3) hydrograph modification and regulation; 4) aquatic introduced species; 5) host species availability; 6) watershed land-use related pollution; 7) disturbance or direct harm; and 8) climate change. This assessment places more weight on threats that already occur as compared to potential or future threats within the range of the Rocky Mountain Ridged Mussel in B.C.

1.5.1 Threat classification

Table 1: Threat classification summary.

1 Foreshore, riparian and littoral zone development		**Threat Information**		
Threat Category	habitat loss or degradation	**Extent**	widespread	
			Local	**Range-wide**
General Threat	loss of natural lake and river shore littoral and riparian habitats	**Occurrence**	current	current
		Frequency	depends on site; recurrent	recurrent
Specific Threat	fragmentation of habitat; habitat conversion; alteration of habitat characteristics; loss of shoreline/littoral habitat; changes to the flow of coldwater inputs to lakes	**Causal Certainty**	high	medium
		Severity	moderate	moderate

Stress	local extinctions; increased mortality; reduced productivity and reproduction; reduced resource availability	**Level of Concern**	high	

2 Historic riverbed channelization		**Threat Information**		
Threat Category	changes in ecological dynamics or natural processes	**Extent**	localized	
			Local	**Range-wide**
General Threat	River channel alteration	**Occurrence**	current	current
		Frequency	continuous	continuous
Specific Threat	loss of mesohabitat variation; substrate instability and scouring; habitat fragmentation	**Causal Certainty**	medium	medium
		Severity	moderate	low
Stress	increased mortality; poor reproductive success; reduced resource availability	**Level of Concern**	high	

3 Hydrograph modification and regulation		**Threat Information**		
Threat Category	changes in ecological dynamics or natural processes	**Extent**	widespread	
			Local	**Range-wide**
General Threat	alteration of hydrograph associated with dam construction	**Occurrence**	historic and current	current
		Frequency	seasonal	recurrent
Specific Threat	Kootenay and Columbia watersheds – fluctuations in water levels prevent the formation of littoral zone along lake and water body shores; all watersheds – diversion/alteration of flows; surface and groundwater coldwater sources; stranding; increased scouring downstream of dams, desynchronized host/parasite interactions	**Causal Certainty**	low-medium (depending on location)	medium
		Severity	unknown	unknown
Stress	increased mortality; decreased reproduction; decreased resource availability	**Level of Concern**	medium	

4 Aquatic introduced species	**Threat Information** – note that impact depends on species involved

Threat Category	Introduced species	**Extent**	localized - widespread	
			Local	**Range-wide**
General Threat	resource competition	**Occurrence**	anticipated - historic	anticipated - historic
		Frequency	unknown - continuous	unknown - continuous
Specific Threat	alteration of habitat characteristics (water quality, vegetation composition, water chemistry); alienation or reduced access to host fish species	**Causal Certainty**	low - high	low - high
		Severity	high - unknown	high - unknown
Stress	reduced population size or population viability; reduced ability of glochidia to disperse; reduced habitat availability	**Level of Concern**	medium	

5	Host fish species availability	**Threat Information**		
Threat Category	changes in ecological dynamics or natural processes	**Extent**	widespread	
			Local	**Range-wide**
General Threat	river channel and waterway alteration; fishing	**Occurrence**	potential - unknown	potential - unknown
		Frequency	unknown	unknown
Specific Threat	alienation or reduced access to host fish species; harvest of host fish species;	**Causal Certainty**	high	high
		Severity	low	low
Stress	poor reproductive success; reduced resource availability	**Level of Concern**	low	

6	Watershed land-use related pollution	**Threat Information**		
Threat Category	pollution	**Extent**	widespread	
			Local	**Range-wide**
General Threat	nutrient and sediment loading; wastewater treatment	**Occurrence**	historic - current	historic - current
		Frequency	ongoing	ongoing
Specific Threat	watershed land-use practises and subsequent sediment/mineral inputs to adjacent waterways (e.g. logging, agriculture, mineral extraction); changes to nutrient inputs (e.g. nutrient loading of nitrogen, phosphorus,	**Causal Certainty**	low	low
		Severity	low	low

	other chemicals); industrial discharges			
Stress	toxic and synergistic effects; reduced productivity; increased mortality; reduced resource availability	**Level of Concern**	low	

7 Disturbance or direct harm		**Threat Information**		
Threat Category	disturbance and persecution	**Extent**	localized	
			Local	**Range-wide**
General Threat	discriminate removal via children/individuals digging, crushing, burying, throwing, etc. mussels	**Occurrence**	low	low
		Frequency	unknown	unknown
Specific Threat	life cycle disruption, damage or injury to individual mussels; mussel inability to reposition itself; microhabitat destruction	**Causal Certainty**	high	high
		Severity	low	low
Stress	increased mortality; poor reproductive success; reduced resource availability	**Level of Concern**	low	

8 Climate change		**Threat Information**		
Threat Category	climate and natural disasters	**Extent**	widespread	
			Local	**Range-wide**
General Threat	climate change	**Occurrence**	unknown	unknown
		Frequency	unknown	unknown
Specific Threat	change in weather patterns; mortality; alteration of habitat characteristics at lake and river shores e.g. less surface runoff	**Causal Certainty**	unknown	unknown
		Severity	unknown	unknown
Stress	poor reproductive success; reduced lifespan; reduced resource availability	**Level of Concern**	low	

1.5.2. Description of threats

The following summaries describe various threats identified for the Rocky Mountain Ridged Mussel in order of their assumed level of concern. It should be noted that in some cases the threats are not independent of others, but efforts to assess each separately have been made to simplify the evaluation.

1) Foreshore, riparian and littoral zone development

Okanagan, Kootenay and Columbia watersheds have undergone substantial development associated with municipal, agricultural, forestry and industrial land uses, all of which have the capacity to alter aquatic habitat directly (e.g. loss of natural shoreline habitat, both riparian and littoral, resulting in the fragmentation of suitable habitat). While the impact of foreshore and riparian development on mussel populations has not been studied, the range of existing lake and river shore developments and their potential impacts are listed below.

a. ***Direct habitat conversion of lakeshore littoral zones*** including: illegal dumping of sand to create non-natural sandy beach habitats, buildings and marinas constructed into lake and river littoral zones, direct removal of lake or stream vegetation, infill with riprap or concrete retaining walls, and illegal construction of groins or breakwaters extending into the water to trap sediments for the creation of beaches, could all directly affect habitat quality and quantity, as well as fragment the remaining littoral habitat for mussels. The impacts are cumulative over the past century. These alterations may also indirectly affect mussels by altering current patterns, wave action and sediment movement.

b. ***Removal of riparian vegetation*** affects light regimes (Strayer, 2008) and can ultimately impact the suspended phytoplankton and aquatic vegetation that live within that zone.

c. ***Alteration of habitat characteristics*** (e.g. construction of piers, floating platforms and marinas that shade aquatic habitat) can lead to vegetation changes. Shade can also impact the aquatic species composition that lives under the pier (e.g. fish refuges, plant growth). Impacts to the littoral zone and riparian areas have been cumulative over the past century.

d. ***Dredging activities*** associated with the construction of marinas or small docks for boats in front of private lakeshore property can directly destroy aquatic habitat.

e. ***Disturbance of littoral substrates*** as a result of excavating and backfilling (e.g. waterlines) can lead to the establishment of Eurasian Water Milfoil - *Myriophyllum spicatum* which can create subsequent alterations to the littoral habitat as upland property owners often want the Milfoil removed or managed.

f. ***Alteration, diversion and collection of precipitation, snowmelt and groundwater*** that would otherwise flow directly into lakeshores may impact the mineral and/or nutrient loading locally. Run-off water that enters lakes through shoreline upwelling also has a moderating effect on seasonal shoreline water temperatures. Removal of riparian vegetation can potentially lead to an increase in siltation in the waterway by exposing the underlying soils to erosion. Ellis (1931) found that molluscs and other benthic organisms declined with the removal of riparian vegetation, due to the subsequent disturbances to the stream bottom. Water quality within systems with riparian vegetation is also documented to be higher than in systems where there is no riparian vegetation (Hunsaker and Levine, 1995).

g. ***Propwashing within the lakeshore littoral zone*** by residents to maintain hull clearance at private docks could have immediate localized impacts through dislodging mussels and their substrates on a regular basis.

h. ***Geothermal heating*** may lead to localized increases in temperature directly around the pipe which may have localized effects on flora and fauna including mussels. This method of heating is becoming increasingly popular with developers. Given that this is a fairly recent approach, no best management practices have been created for such developments (Robbins pers. comm. 2009a).

In general, high impacts to fish habitat in tributary streams of Okanagan Lake from urban and agricultural activities are noted at low elevations, whereas moderate impacts by urban, agricultural and forestry activities are noted at higher elevations (Rae, 2005). The shores of Okanagan Lake support the three largest urban centres in the basin: Kelowna, Penticton and Vernon. Shorelines are altered by beach development and maintenance, docks, and armouring for roads. These types of development can alter wave patterns and can reduce shoreline stability, thereby increasing sedimentation and erosion. An estimate in the mid-1990s indicated that 80% of the lake's south-western and northern shoreline had been altered in some way (Rae, 2005). With the 1958 channelization of the Okanagan River, 85% of the riparian vegetation was also lost (Rae, 2005).

Direct mortality results when mussels are buried in sand/substrate or by dredging along lakeshores (as shown in Krueger *et al.,* 2007). Studies show physical disturbance can lead to decreases in reproduction and detrimental effects on glochidia (Hastie and Young, 2003 as read in Kruger *et al.,* 2007). Poor reproductive success can subsequently occur due to the inability of sperm to disperse due to turbidity, as unsuitable habitat does not attract host fishes for the glochidia life-stage. Furthermore, a recent study found that Rocky Mountain Ridged Mussels are particularly sensitive to disturbance during the brooding of embryos and may abort them (Spring Rivers Ecological Sciences, 2007). It is unknown both if Rocky Mountain Ridged Mussels occur at water depths beyond the littoral zone and if there are any detrimental impacts which lakeshore development has on populations at greater depths. Further study is needed to determine the threats to these substrate habitats.

Overall, the extent of each specific threat to the shoreline is likely localized (not along all lakeshores), but from a cumulative perspective the overall impact is considered extensive. In addition, all watersheds have extensive development pressures that will significantly increase over the next twenty years. Unfortunately, a compliance study conducted in 2008 on Okanagan and Skaha lakes for riparian and foreshore development found that almost 100% of the shoreline developments evaluated were out of compliance (e.g. either had not applied for a B.C. *Water Act* permit, or in a few cases a permit was obtained but development was not in compliance with the permit). Specifically, of the 35 properties randomly selected for a 30 km length of developed shoreline on Okanagan Lake, all were out of compliance. Similarly, of the 194 sites comprising the entire shoreline of Skaha Lake, 99.9% had no applications (Nield, 2009). While the habitat impacts of the non-compliant developments were not assessed, the results underscore the challenge of managing the development pressure. The Okanagan Region Large Lakes Protocol (available at http://www.env.gov.bc.ca/okanagan/esd/ollp/documents/Foreshore-protocol-May2009.pdf) guides development and over an implementation period of approximately one year has curtailed some non-compliance, particularly with docks and marinas (Robbins pers. comm. 2009b). Monitoring and auditing of the Riparian Area Regulation for developments above the high water mark is also undertaken by the Province of B.C. (Robbins pers. comm. 2009b).

The cumulative impacts of lake and river shore development could ultimately lead to a reduction in population size and viability at a given location. Impacts could include a decline in the amount and quality of substrate for mussels to bury and seek protection, increased mortality at all life stages due to predation pressures, inability to disperse during the glochidia life stage, or an inability to bury/establish during free-living benthic life stage.

2) Historic riverbed channelization (i.e. effects of altered river morphology)

This section considers how the altered morphology of rivers associated with channelization may impact the Rocky Mountain Ridged Mussel. Flow and water level regimes associated with the operation of dams (including those used for flood control) are discussed in threat (3) *hydrograph modifications and regulation*. Threats associated with river channelization are not well understood although there are some obvious impacts to the Rocky Mountain Ridged Mussel. Within its global range, the Rocky Mountain Ridged Mussel characteristically inhabits large, slow moving, shallow rivers (COSEWIC, 2003). Yet in contrast, most confirmed records from B.C. sites (with the exception of the Okanagan River) occur in large lake habitats (B.C. Conservation Data Centre, 2009). It is possible the Rocky Mountain Ridged Mussel historically inhabited larger river systems in B.C. (e.g. the Okanagan, Kootenay and Columbia rivers), yet due to channelization, damming, and flow regulation the species now remains within habitats that may not be preferred habitats (e.g. large lakes).

In 1958, channelization of the Okanagan River to prevent major flooding was completed (Rae, 2005). The once meandering river with a broad flood plain was reduced to a canal with few habitat features such as riffles, pools or eddies. The length of the river was reduced from 61 km to 41 km, and approximately 93% of the original channel has been altered to some degree (Rae 2005). As a result, the channel now has a higher gradient than the original river, and 17 concrete weirs were constructed to ease the steepness. The channel was dredged, dykes were built on either side of the channel, and as noted above, 85% of riparian vegetation was lost. These changes, along with the extensive urban and agricultural development adjacent to the channel, have resulted in higher water velocities with little or no hydraulic refuges for potential host fish, a higher potential for scouring effects, and altered temperature regimes.

Channelization has been shown to lead to the decline of other mussel species. Strayer and Ralley (1993) concluded streambed changes led to the decline of the Brook Floater (*Alasmidonta varicose*) and Dwarf Wedgemussel (*Alasmidonta heterodon*) in the northeast United States. Similar research has not been completed on the Rocky Mountain Ridged Mussel.

There is an initiative to restore the Okanagan River called the Okanagan River Restoration Initiative (ORRI). Phase 1 of the ORRI re-meandered 1.2 km of diked river channel to a final length of 1.4 km between 2008-2009. This included the reconnection of two oxbow lakes to create a dual channel with two islands, a diversity of habitat types and a wider floodplain for 600 m of river (Mathews pers. comm. 2010). No drop structures were removed in this process (Mathews pers. comm. 2010). Phase 2 involves channel reconstruction of an additional 600 m of river upstream of Phase 1 and modification of a vertical drop structure; this work will be initiated in 2010. Prior to any modifications, these river sections were surveyed for fish and mussels in 2006; and no mussels were detected during the survey (Dyer pers. comm. 2008). It is possible that new meanders may change the habitat potential for the mussel and increase available habitat. The realignment could also decrease velocities enhancing access through the area for potential host fish. As previously mentioned, the Rocky Mountain Ridged Mussel is a large river species in the southern parts of its range, and thus the restoration of larger rivers may increase our understanding of its historic habitat occupancy.

3) Hydrograph modification and regulation (effects of dam operation)

This section considers how flow delivery and water levels associated with dam and weir operations, as well as water diversions, may affect aquatic habitat. Hydrology in the Okanagan, Kootenay and Columbia rivers has been highly modified over the past century. In the case of Kootenay and Columbia rivers, these manipulations are mainly associated with major hydro-electric facility development and maintenance. In the Okanagan Basin however, manipulations are mainly in response to water demands for irrigation and domestic purposes, as well as flood control in urban areas.

The damming of a river and subsequent creation of a large lake leads to downstream habitats dominated by boulders and cobbles and an increased sediment load upstream of the dam (Parmalee and Hughes, 1993; Blalock and Sickel, 1996 as cited in Watters, 2000). The overall impact that dam construction and flow alteration has on molluscs depends on the type of dam (Watters, 2000), where the outlet for the dam is (e.g. is the flow outlet under water or a cascade of water flowing from above water), the seasonal period of flow, and the length of time since the dam has been in place (i.e. mussels are generally long lived and grow slowly, and changes to mussel beds may not be evident for many years) (Strayer, 2008). Upstream effects (e.g. in a lake or reservoir) will also depend on releases from the dams.

There are numerous large hydro-electric dams and associated power generating facilities on Kootenay and Columbia rivers. Flows downstream of dams in riverine sections can vary daily, weekly, and seasonally depending on the specific facility; this can result in stranding along river margins and scouring effects, depending on ramping rates. Similarly, draw-downs particularly in the Arrow Lakes' reservoir are significant (i.e. many meters) and could strand sessile organisms like mussels. Such highly variable environments are not conducive to the establishment of stable margin habitat and can result in lake-like conditions with very low productivity. Reservoirs also tend to act as sediment traps resulting in increasing water clarity downstream of the dam, but increasing layers of sediment within the reservoir. Not only will these variable altered habitats affect mussel distribution, they may also alter and fragment host fish distributions.

Flow regulation in the Okanagan Basin associated with dams is not to the same scale as seen in the Columbia River, but may still affect mussel distribution. Specifically, Penticton Dam has been maintained at the outlet of Okanagan Lake for decades; this dam helps control flooding and stores water for low flow periods. However, annual flow manipulations result in variable water levels particularly in Okanagan Lake (Rae, 2005). Similarly, Skaha, Vaseux and Osoyoos lakes all have outlet dams to regulate flows (respectively Okanagan Falls, McIntyre and Zosel dams). While stranding and resulting desiccation of mussels in shallow littoral habitats is a potential concern when lake levels are drawn down, current targets associated with timing, rate, and magnitude of drawn-downs are not expected to have significant impacts (McKee pers. comm. 2009). In a typical year, the level of Okanagan Lake is now dropped less than 1 m total based on the current Okanagan Lake Regulation System Operating Plan (McKee pers. comm. 2009). Although this used to be a staged process through the late fall and winter, the drop is now usually completed prior to Kokanee lakeshore spawning in October to ensure eggs are not exposed during the winter (McKee pers. comm. 2009); this guideline probably also protects most mussels from desiccation. Specifically, mussels do have a limited capacity to track water levels while water temperatures are still relatively mild (i.e. late summer/early fall); therefore, those that are within the very shallow areas (i.e. less than 1m depth) during the summer/early fall could move to greater depths as water levels are dropped thereby preventing them from being exposed during the winter. However, if water levels were to be dropped during the winter when the mussels' ability to track water levels has effectively ceased, those residing in depths less than 1m could become desiccated. In years of extremely high snowpack, additional water is still released from the lake during winter (February); this may increase the likelihood of desiccation for mussels in less than 1 m of water, either through direct exposure or freezing in sheltered bays where the surface of the lake does freeze (McKee pers. comm. 2009). Skaha and Vaseux lakes may experience more frequent changes in water level, however significantly less than Okanagan Lake, with targets of 10 cm and 20 cm respectively as outlined in the aforementioned Okanagan Lake Regulation System Operating Plan (McKee pers. comm. 2009).

In terms of releases downstream of Okanagan Falls and McIntyre Dam, scouring is likely a significant factor that could impact mussels in Okanagan River, particularly during spring freshet (April-June) if the lake starts to flood (McKee pers. comm. 2009). Small concentrations of Rocky Mountain Ridged Mussel shells with the nacre rubbed off have been observed in the channelized section of the Okanagan River on the riverbed surface in the margins, possibly indicating prior scour (Pollard pers. comm. 2009). Furthermore, surveys conducted for the mussel in August 2009 in the remaining stretch of natural river channel below McIntyre Dam noted very limited depositional areas with sediment where mussels might be able to settle, suggestive of regular scouring events (Pollard pers. comm. 2009). Finally, with respect to the outlet dam on Skaha Lake, MacIntyre Dam at the outlet of Vaseux Lake, and Zosel Dam located below Osoyoos Lake, only Zosel Dam is currently managed for upstream movement of migratory fish and the remainder are considered barriers to upstream fish movement most of the time (Rae, 2005).

4) Aquatic introduced species

Introduced aquatic species already inhabit most waterways within the Okanagan, Kootenay and Columbia River systems (B.C. Conservation Data Centre, 2009). These consist of several non-native fish species such as the Common Carp (*Cyprinus carpio*), Black Crappie (*Pomoxis nigromaculatus*), Largemouth Bass (*Micropterus salmoides*), Smallmouth Bass (*Micropterus dolomieui*), and Yellow Perch (*Perca flavescens*), as well as Eurasian Water Milfoil. Most of these species have been in these river systems for decades; however, the global trend is an increasing spread of non-native species, and the Okanagan Basin is no exception. While many non-native species may prove to be relatively benign, there are several considered to be highly invasive and potentially devastating to native ecosystems should they become established. The following list identifies species considered invasive that potentially could impact the Rocky Mountain Ridged Mussel. The overall moderate level of concern for this threat reflects the fact that the species of greatest concern, namely Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*Dreissena rostriformis bugensis*), are currently not present in B.C.. With respect to existing non-native species listed below, it is unclear as to the impact their presence may already have had, or is having on the Rocky Mountain Ridged Mussel. In summary, aquatic introduced species that potentially do, or may affect the Rocky Mountain Ridged Mussel include:

a. ***Eurasian Water Milfoil*** which has spread throughout many freshwater systems in B.C. and eventually grows into thick dense stands in depths 0.5 – 10 metres. The plant reproduces vegetatively, both through shoots and stolons that creep along the waterway bed, or through the fragmentation and passive dispersal of its feathery stems (Aiken *et al*., 1979).

   Eurasian Water Milfoil affects the natural ecological processes within a water system through changes to both water quality and the physical structure of the underwater habitat. Overall, the plant out-competes and displaces aquatic macrophytes within an area (Aiken *et al*., 1979; Miller and Trout, 1985; Hanna, 1984; Madsen *et al.,* 1991), disrupts predator-prey dynamics (i.e. many larger fish are kept out of its dense stands), may affect spawning cycles in native fish (Newroth, 1985), and changes water chemistry causing algal blooms (Environment Canada [EC], 2008). The plant causes alteration of habitat characteristics (water quality, vegetation composition, water chemistry, oxygen content), which can potentially: reduce the availability of suitable substrates, compete for available nutrients, and alienate or reduce access to the host fish species. Potential effects of these changes may include reduced population size or population viability of the mussel, reduced ability of glochidia to disperse, poor reproductive success, and overall reduced resource availability. Management of Eurasian Water Milfoil may also pose a threat through rototilling of the substrate where mussels could exist and/or through the suspension and redistribution of bottom sediments.

b. ***Largemouth Bass and Smallmouth Bass*** which are established in the Okanagan, Kootenay and Columbia River watersheds (B.C. MoE, 2008). Both these species are aggressive predatory fish that may compete with and predate on native fish and amphibians. Largemouth bass are known to directly and indirectly influence the abundance and distribution of other fish species (Harvey, 1991). Without information on the potential host fish however, it cannot be determined if Large- and Smallmouth bass have an adverse effect on the host fish of Rocky Mountain Ridged Mussels; these species may, in fact, act as alternative hosts.

c. ***Zebra Mussel and Quagga Mussel*** which have not been reported in B.C. (100^{th} Meridian Initiative, 2009) lthough a recent modelling exercise based on a limiting mineral calcium predicts a high likelihood of establishment of these mussels in the Okanagan drainage if introduced (Matthias Herborg, upublished data, 2009). Both species continue to spread west and north from their original points of introduction in eastern North America. The first Californian population of Zebra Mussel was reported in the San Justo Reservoir in January 2008 (US Geological Survey, 2009). Similarly, California now has populations of Quagga Mussel in numerous lakes since it was first discovered in January 2007 (US Geological Survey, 2009). Zebra and Quagga mussels have caused worry amongst conservation officials as they have extirpated native unionid mussels in areas they infested such as the Great Lakes Region (Ricciardi et. al., 1998; Schloesser et. al, 2006).

d. ***Asian clam* (Corbicula fluminea)** which is a small (usually < 3 cm) freshwater bivalve that has spread into lakes, waterways, large rivers, and estuarine habitats throughout parts of North America (Carlton, 1992). The Asian Clam inhabits a variety of freshwater substrate types, including gravel and sand substrates, and large river areas (Hornbach, 1992), overlapping habitat types with the Rocky Mountain Ridged Mussel. The Asian Clam is known to displace native molluscs for space and food (Strayer, 2008). The Asian Clam has been reported throughout Washington State (Foster et al., 2008) and within the lower mainland region of

B.C. (B.C. Conservation Data Centre, 2009), but is not yet known from the southern interior.

5) Host species availability

Threats to host fish and the influence these threats have upon the overall decline of the Rocky Mountain Ridged Mussel are not well understood. In general, fish composition and populations within the Canadian range of the Rocky Mountain Ridged Mussel have changed over the past century. Direct impacts include the harvest of fish from sport fishing, while indirect impacts include competition from introduced fish (e.g. bass) and other habitat altering factors (discussed above). Host fish are a vital component to the completion of a mussel life cycle, although host fish are not considered equally important in supporting mussel recruitment (Strayer, 2008). Numerous factors determine the effectiveness of a host fish including the species' abundance, seasonal patterns, and actual exposure to mussel glochidia (Strayer, 2008). Although not well understood, host fish can also develop resistance to glochidia infections, as well as intraspecific immunity between host fish (Strayer, 2008); these and other factors need to be identified and further studied.

With respect to possible host species for the Rocky Mountain Ridged Mussel, the native species composition in both Okanagan Lake and the Okanagan River has remained constant, with the addition of several non-native species (Mitchell pers. comm. 2009). With the exception of the Kokanee fish population in the lake that has experienced a significant decline since the 1980s, no trends in the abundance of native fish have been observed. Fish that utilize the shallow littoral areas in the lake include sculpin species, night-feeding Rainbow Trout, sucker species, exotic Yellow Perch and exotic Smallmouth Bass (Mitchell pers. comm. 2009). In conclusion, a significant reduction or extirpation of host species would have major ramifications to the mussel population in the Okanagan Lake, and indeed elsewhere the loss of hosts has resulted in local extirpations for some mussel species (Strayer, 2008 and references therein). There is no evidence, however, that the native fish populations in the Okanagan Basin have suffered the magnitude of decline or extirpations likely necessary to impact mussel distribution or abundance. Furthermore, most native (and non-native) fish species are still found in river sections considered fragmented by weir and dam placements and there is no expectation that large scale changes in fish composition should be expected in the near future (Mitchell pers. comm. 2009).

6) Watershed land-use related pollution

Land-use practices potentially impact the capacity of aquatic habitats to support life by altering water quality. The introduction of deleterious substances, broadly defined as pollution, to the aquatic environment may include toxins, nutrient loading, and sediment loading. Sources of pollution into water bodies have origins that may be point source (single identifiable, localized source of pollution) or non-point source (diffuse, non-identifiable origins), each of which can contribute to the cumulative pollution level.

Within the range of the Rocky Mountain Ridged Mussel, point source and non-point source type pollution varies with the watershed. Within the Kootenay River, hydroelectric activity, mining and forestry are the predominant historic and ongoing anthropogenic influences on water quality (Ministry of Environment, Lands and Parks [MoELP] and EC, 2000). In the Columbia River drainage, hydroelectric, forestry, municipal, industrial, and agricultural activities are the predominant anthropogenic influences on water quality. Within the Okanagan River, agriculture, municipal waste water and storm water discharges, septic tanks and tile fields, and forestry are pollution contributors (MoELP and EC, 2000).

Nutrient, sediment, and deleterious substance loading from chemicals leached via storm water run-off through agricultural, de-forested, and urban lands into adjacent waterways are considered non-point source and these contaminants can have significant cumulative impacts on water quality. For example, Osoyoos Lake has the highest nitrogen content of the Okanagan River watershed lakes (Rae, 2005), and is warmer than Skaha or Okanagan Lakes. Although high nutrient levels are partly the result of lake morphology (very shallow), surrounding agricultural and urban run-off likely contribute to this condition. The highly productive, shallow condition of Osoyoos Lake allows for a higher rate of decomposition of the organic material that has settled on the bottom of the water body, which ultimately results in reduced oxygen levels, particularly in the warmer summer months (Rae, 2005). As a result the north end of the lake historically turned anoxic but now becomes depleted for the bottom 20 m; however, the layer above the thermocline never suffers from anoxia (Jensen pers. comm. 2009). Given the unknown status and maximum depths used by the Rocky Mountain Ridged Mussel, it is impossible to determine if this is a limiting factor in Osoyoos Lake, although it does affect the fish in the system.

Point-source pollution originates from discharge sites associated with wastewater management, mining, pulp and paper production and other industries, and accidental chemical spills. Point source pollution is not as prevalent as it was in the early part of the nineteenth century, primarily due to higher discharge standards set by all levels of government. Present day point source pollution is typically the result of an accidental chemical spill, industrial chemical leaks, or effluent releases associated with sewage and mining activities. In the Kootenay River near Fenwick Station the kraft pulp mill at Skookumchuck is the main potential influence on water quality (MoELP and EC, 2000). The Teck Cominco Sullivan mine at Kimberley closed in 2001 with Teck Cominco currently operating a drainage water treatment plant in the spring and fall to treat mine run-off (MoELP and EC, 2007). Although not regular, acid and other contaminants do occur on occasion from various mining operations e.g. May 2008 leak into the Columbia River of acid and lead from the Teck Cominco smelter in Trail (Spokesman Review, 2008). Within the Columbia system, there has been waste abatement at the Cominco smelter-fertilizer complex resulting in an improving trend in water quality near Waneta for metals, phosphorous, and major ions (MoELP and EC, 2000).

Point source pollution in the Okanagan drainage historically included wastewater discharge. Tertiary sewage treatment implemented in the 1980s has reduced nutrient load largely from Okanagan Lake, such that it is no longer a concern for water quality. Brenda Mines was an open-pit mine which extracted copper and molybdenum from 1970 to 1990; approximately 200 million tonnes of ore was processed during this time (Patterson, 2003). Treated water from the mine's tailings pond originally flowed into Trepanier Creek (Rae, 2005); since 1998 a water treatment facility has been installed and molybdenum concentrations are reported as below B.C. drinking water guidelines (Xstrata Copper, Brenda Mines, 2008). No other mining operations influence water quality in the Okanagan Basin; however, storm water run-off associated with urban areas is expected to increase with ongoing urban expansion (Jensen pers. comm. 2009).

Water quality within all three major drainage systems has been monitored at numerous sites for over 20 years (MoELP and EC, 2000). Seven of the sites directly within the rivers were indexed as to the overall suitability to support aquatic life; with either Fair or Good determined by MoELP and EC (MoELP and EC, 2007). However, it should be noted that some specific constituents were not consistently within safe levels (MoELP and EC, 2000). Furthermore, monitoring results are not representative of the entire watershed, and pollutant levels could vary significantly at other sites (MoELP and EC, 2000). Thus it is difficult to evaluate to what degree pollutants might affect mussel presence in British Columbia. However, as the following section indicates, the species is sensitive to certain constituents.

The effect of anthropogenic toxins on mussels includes a large body of literature that is summarized in Strayer (2008). Strayer (2008) emphasizes there are "three especially worrisome classes of pollutants [that include] unionized ammonia (NH3), toxic materials with a high affinity for sediments, and endocrine disruptors". All of these substances are associated with agricultural and urban run-off via fertilizers, pesticides, antifouling agents, other agricultural pharmaceuticals, and detergents (Strayer, 2008). Some of these pollutants concentrate in sediments because of their reduced solubility in water and may persist for long periods after the source of contamination has been removed and may be particularly toxic to juvenile life history stages that feed directly on sediments (Strayer, 2008). Agricultural run-off and sedimentation are the predominant factors threatening mussels in eastern North America (Richter et al., 1997). In general, toxicants cause reduced growth rate, respiration and metabolism, tissue deterioration and eventual death in mussels (Fuller 1974; Goudreau *et al*., 1993). The long-term, cumulative effects of non-point source pollution on mussels could take years to become evident given their long life-span and the associated long lag in response to pollution change (Strayer, 2008).

The early life history stages of freshwater mussels (i.e. glochidia and recently settled juveniles) appear to be acutely more sensitive to certain chemicals than other commonly tested aquatic organisms (Wang et al. 2007 a, b and references cited therein). As such, recent attempts to establish toxicity levels of certain contaminants including copper, ammonia and chlorine, for mussels have been undertaken with recommendations for updating water quality standards to meet mussel needs (Wang et al. 2007a, b). In light of this, a comparison of lowest concentrations at which effects were observed in freshwater mussels was compared to measured levels of a commonly measured toxin copper in various Okanagan Lake tributaries (Jensen pers. comm. 2009). Some tributaries

(Kelowna, Peachland and B-X creeks) may experience concentrations of copper considered to be at low chronic effects for mussels (i.e. approximately 8.5-9.5 parts per million); however, most tributaries are in the range of 2-3 parts per million and dilution in the lake results in considerably lower levels (Jensen pers. comm. 2009). In terms of nutrient loading as it relates to the Okanagan Basin, there may be some localized nitrates associated with agricultural run-off but these effects are isolated to specific tributaries; upon reaching the lake, such levels become highly diluted and in many cases is no longer an issue as best management practices are adopted (Jensen pers. comm. 2009). Some pharmaceuticals such as endocrine disruptors in sewage may be of concern particularly in localized areas downstream of the treatment plants at Okanagan Falls and in Penticton, and studies to consider levels is underway currently (Jensen pers. comm. 2009).

7) Disturbance or direct harm

Disturbance or direct harm to the Rocky Mountain Ridged Mussel includes the displacement of mussels by digging, moving, burying, collecting and crushing mussels or mussel beds. Examples of disturbance or direct harm include children collecting and piling live mussels, and further throwing mussels from the shoreline into the water and thus into habitat with unsuitable substrate. Although not considered a substantial threat, further education and interpretive materials need to be developed to inform beach users and patrons of the importance of the Rocky Mountain Ridged Mussel and the threats to the species.

8) Climate change

Climate change will affect water temperature, lakeshore littoral zone vegetation and stream hydrograph patterns in the future. Changes to stream hydrograph patterns in the Okanagan have already been attributed to climate change i.e. earlier freshet and lower autumn flows, and are expected to continue in the future (Rae, 2005). With respect to the Rocky Mountain Ridged Mussel, changes in water temperature will impact reproductive success and the timing of life history events (Strayer, 2008) and potentially lead to mussel life cycles being desynchronized with seasonal temperature patterns. Changes to the hydrograph could also affect temperatures and habitat stability. Climate change is a poorly understood threat, although research that models scenarios that combines water management demands, changing temperature and rainfall regimes, host fish distribution and other factors, may assist with predicting and prioritizing habitat protection for the Rocky Mountain Ridged Mussel.

1.6 Actions Already Completed or Underway

1) Records compiled for the Rocky Mountain Ridged Mussel 1905 – 2009. Compilation by Lea Gelling, B.C. Conservation Data Centre, B.C. MoE 2009.
2) Surveys undertaken for the Rocky Mountain Ridged Mussel 2005 – 2009, Okanagan River watershed. Conducted by B.C. MoE (2005 – 2009).

3) Broadbrush surveys undertaken for the Rocky Mountain Ridged Mussel within the Okanagan River watershed and Kootenay area, B.C. Conservation Corp. Conducted by Invertebrate Species at Risk survey crew (Moore and Machial, 2007).
4) Status report for the Rocky Mountain Ridged Mussel updated by L. Gelling, S. Pollard, and L. Ramsay for COSEWIC. Submitted in December 2009 for review.
5) Mussel surveys undertaken within the Okanagan, Kootenay and Columbia River watersheds in 2008. Conducted as a joint project with B.C. MoE and DFO.
6) Public participation, freshwater mussel information and specimen reporting project undertaken in the summer and fall of 2008. Information packages were sent to various interest groups throughout the province, including B.C. MoE volunteers (e.g. parks staff, biologists), naturalist groups, dive shops, and other interested groups to collect freshwater mussel shell samples and data. The goal was to have volunteers return the samples to the B.C. Conservation Data Centre for identification and compilation of data.
7) Terms and Conditions for *Water Act* notifications set by B.C. MoE, Okanagan Region that include: salvage and relocation of live mussels following a protocol developed by DFO and; dock design criteria requiring light penetrating decking in high value kokanee spawning areas that also benefits any coexisting mussels (Robbins pers. comm 2010). This can be found in sections E and H within the following link http://www.env.gov.bc.ca/wsd/regions/okr/wateract/terms_conditions_okanagan.pdf. The areas with live mussel records are found in the red zones within the Okanagan Region Large Lakes Protocol (Robbins pers. comm. 2010).

Numerous planning and habitat protection tools indirectly benefit the Rocky Mountain Ridged Mussel, improve or protect habitat condition and address flow issues:

- Okanagan River Fish Water Management Tool. This model balances concerns for recreation, flood management and fish needs and could potentially be modified to address mussel concerns if identified.
- B.C. MoE regional best management practices for installation and maintenance of water line intakes available at the following: http://www.env.gov.bc.ca/wld/documents/bmp/BMPIntakes_WorkingDraft.pdf
- Habitat restoration efforts (as described earlier in 1.5.2.2, Threats, Historic riverbed channelization).
- Environmental farm planning which provides for improved land management practices.
- Water Use Planning which is currently applied to Trout Creek, and is being considered on other Okanagan River tributaries including Mission Creek.

1.7 Knowledge Gaps

Table 2: Rocky Mountain Ridged Mussel knowledge gaps.

Biology	• Life history including specific months and environmental triggers for spawning, fertilization, glochidia dispersal and occupancy of host fishes. • Host fish(s) in B.C. including potential non-native species. • Lifespan, growth and reproductive capability (sperm and egg production), glochidia survival, dispersal ability. • Food requirements and preferences. • Parasites or commensals such as nematodes, leeches, flukes, mites, distomids and flatworms are known to live within freshwater mussels (Strayer, 2008). The types of parasites and effects of parasites on the Rocky Mountain Ridged Mussel are unknown.
Habitat requirements and status	• Quality of water habitat including water temperature, levels of dissolved nutrients, oxygen and other minerals necessary to maintain healthy mussels. • Aquatic substrate habitat description including substrate composition, location of occupancy within the littoral zone and at deeper depths. • Refined mapping of known sites and the development of a habitat quality rating system (e.g. good, moderate, poor and developed (no longer suitable). • Determine preference for cold water habitat requirements; the Rocky Mountain Ridged Mussel appears to favour coldwater habitats although specific temperature information is undocumented for B.C. • Importance of the proximity of surface and ground coldwater sources to aggregations of mussels.
Species status and distribution	• Determine the parameters around defining a Rocky Mountain Ridged Mussel location. • Clarification and delineation of area of occupancy at each site where populations greater than 100 individuals. • Standardized protocol to measure population estimates within areas where the mussel occurs at numbers greater than 20 individuals. • Develop a prioritized list of habitats to survey, using GIS mapping applications, and complete further inventory throughout the Okanagan River, Columbia River and Kootenay River watersheds. The Similkameen River watershed and Vancouver Island area should also be surveyed for mussels. • Further survey work using submersible video, expanding the area covered with a greater depth range and potentially wider area. Diver and video data should be calibrated against each other to ensure comparability.
Clarification of threats and limiting factors	• Nutrient loading and whether this is a detriment to populations, or benefit (may increase productivity). • Clarify species-specific threats, including parasites and diseases, pollutants, recreational activities, invasive species, and impacts from sedimentation caused from disturbance of substrate in the littoral zone, both downstream and upstream from large populations. • Expansion of research on habitat restoration potential, including methods for

	reducing threats and impacts from recreational activities, dredging, pollutants and sedimentation. • Clarify if non-native fish species are glochidia host fish. • Clarify length of glochidia survival if host fish dies.
Other	• Aboriginal traditional knowledge regarding Rocky Mountain Ridged Mussel historic distribution and trends, whether shells were traded, occurrence in First Nations middens, and cultural importance.

2. MANAGEMENT

2.1 Management goal

The management goal for the Rocky Mountain Ridged Mussel is to *maintain viable, self-sustaining, ecologically functioning and broadly distributed populations within suitable habitats at the species' current distribution and range in B.C.*

With respect to this goal, the current range of the Rocky Mountain Ridged Mussel includes the Okanagan River watershed, from the northernmost record of a shell found in Vernon to the southernmost record of a shell found in the Osoyoos area. The range extent will be expanded if occurrences are found in the Kootenay or Columbia River watersheds, or the historic record from Vancouver Island is confirmed.

2.2 Objectives

1) By 2015, address knowledge gaps about the life history, provincial range and threats to the Rocky Mountain Ridged Mussel.

2) By 2015 inventory 75% of potential littoral habitat within the Okanagan River watershed, with standardized protocol for habitat and threat information collected at each site searched.

3) By 2015, demonstrate an increased number of stewardship activities initiated and completed for land managers and public users of habitats occupied by the Rocky Mountain Ridged Mussel.

4) As research and inventory results on Rocky Mountain Ridged Mussel become available, incorporate into land-use planning to inform future threat mitigation and land use protection.

2.3 Actions

Actions to recover the Rocky Mountain Ridged Mussel are outlined in six categories 1) Protection; 2) Management; 3) Research; 4) Monitoring and Assessment; 5) Outreach and Communication; and 6) Restoration (see Table 3). As can be gained from previous sections, there is substantial uncertainty related to the life-history, distribution, limiting factors and threats to the Rocky Mountain Ridged Mussel. Therefore, the overall approach described below is to focus additional actions on addressing that uncertainty in the implementation stage e.g. through research, monitoring and assessment. This should then provide a good foundation for future management actions.

2.3.1. Protection

Measures exist to protect the Rocky Mountain Ridged Mussel and its habitat. These include both federal and provincial legislation, protocol and guidelines. While most of these measures consider fish and fish habitat in general, some guidelines under regional protocols consider the Rocky Mountain Ridged Mussel specifically. As noted in Section 1.5.2.1 monitoring and auditing is also undertaken on protection measures.

1) Federal protection:
    a. *Fisheries Act*
    b. *Canadian Environmental Assessment Act*
2) Provincial protection:
    a. *Fish Protection Act* and *Riparian Areas Regulation*
    b. *Water Act* and *Water Protection Act*
    c. Under *Riparian Areas Regulation* of the B.C. *Water Act*, the regional *Okanagan Region Large Lakes Foreshore Protocol* was developed and is available at: http://www.env.gov.bc.ca/okanagan/esd/ollp/documents/Foreshore-protocol-May2009.pdf. This document requires proponents of project proposals below the high water mark to follow specific protocols according to type and location of activity with respect to sensitive fisheries zones, including the Rocky Mountain Ridged Mussel. For large-scale projects (e.g. multi-slip docks, marinas), the proponent must also undertake a wave/wind/sediment study to consider potential changes associated with the project (Robbins pers. comm. 2009a).

There are also policy initiatives that could include the Rocky Mountain Ridged Mussel to enhance its protection, such as:

1) Incorporate mussel considerations into the Okanagan Sustainable Water Strategy and Okanagan Water Supply and Demand Project, directed by the Okanagan Basin Water Board (http://www.obwb.ca/index/)
2) Disseminate information about the Rocky Mountain Ridged Mussel and the species' habitat needs, to habitat protection officials at all levels of government who are implementing measures under the provincial *Riparian Areas Regulation*, *Forest and Range Practices Act* or agricultural policy (B.C. Ministry of Agriculture and Lands, 2008).
3) Encourage water managers to consider mussel conservation in water allocation decisions.
4) Incorporate mussel management provisions into best management practices and guidelines, including riparian development guidelines, at all levels of government.

2.3.2. Management

Management actions for the Rocky Mountain Ridged Mussel involve a multi-jurisdictional approach at all levels of government. Provisions for the Rocky Mountain Ridged Mussel should be further integrated into existing federal, provincial, regional and municipal planning documents and guidelines. Mussels are included in the Okanagan Region Large Lakes Foreshore Protocol and sampling protocols are given to those who submit applications for marinas, docks, dredging or lakeshore development applications to B.C. MoE (Nield pers. comm. 2009).

2.3.3. Research

There are substantial knowledge gaps for the Rocky Mountain Ridged Mussel (Section 1.7). Priority research will focus on life history and host fish(s), habitat mapping, clarification of threats to both the species and the host fish(s), and inventory throughout the species range in Canada. Mollusc inventory is needed in the Kootenay, Columbia, Similkameen and lower Thompson River systems. Further inventory on southern Vancouver Island is also needed to confirm absence of the mussel or to confirm the possibility this historic record has likely been traded (a shell dated ~1890 is housed at the University of Michigan Museum of Zoology).

While investigating these knowledge gaps, efforts to increase research interest from academics will continue. At present, captive breeding to supplement the wild populations and locations is neither under consideration nor thought necessary for the management of the Rocky Mountain Ridged Mussel. Captive breeding may take place to gain knowledge regarding this species life history and reproductive capabilities, and this research would need to be done within the watershed the specimens originated. Translocation of specimens within or between watersheds is also not considered a priority, although a decision analysis and discussion paper needs to be researched to determine if this research activity would be beneficial.

2.3.4. Monitoring and Assessment

Monitoring and assessment actions aim to improve and implement existing standardized population and habitat assessment protocols (e.g. Fish Inventory Data Standards [FIDS]; Conservation Data Centre mollusc reporting forms) to monitor the population(s) throughout the species known range in Canada. Ongoing monitoring is needed in known locations with live Rocky Mountain Ridged Mussels throughout the Okanagan watershed.

2.3.5. Outreach and Communication

Stewardship involves the voluntary cooperation of all Canadians to protect species at risk and the ecosystems they rely on. It is recognized in the *Canada - British Columbia Agreement on Species at Risk* that: “Stewardship by land and water owners and users is fundamental to preventing species from becoming at risk and in protecting and recovering species that are at risk” and that “cooperative, voluntary measures are the first approach to securing the protection and recovery of species at risk” (EC, 2009). Stewardship actions include following guidelines or Best Management Practices to support species at risk; voluntarily protecting important areas of habitat; conservation covenants on property titles; ecogifting of property (in whole or in part) to protect certain ecosystems or species at risk; or sale of property for conservation.

Public education and stewardship initiatives will target citizens who will have immediate impact on protecting the species, including those in the sport fishing community, land owners/managers of lake and river shore property adjacent to live mussel colonies, public lands managers (e.g. of beach and recreational properties) and resource professionals working and living within regional districts and municipalities. Outreach and communications strategies aim to complement the protection actions (Section 2.3.1). To this end, the Province of B.C. has extended its distribution and communication to the public regarding the Okanagan Region Large Lakes Foreshore Protocol (Robbins pers. comm. 2009a).

Ongoing outreach includes the distribution of mussel information pamphlets to dive shops, marinas, government (all levels) and resource professionals. Interpretive materials and signs posted at beaches and lakeshore with mussel populations will also be posted, and specifically target those who may dig, bury or displace mussels found in that area.

2.3.6. Restoration

Rocky Mountain Ridged Mussel habitat in B.C. primarily includes muddy and soft bottomed substrates overlayed with a mix of cobble, gravel and sand, within the littoral zone of a lakeshore or river way. This same habitat is often not considered favourable by lakeshore recreational properties, and activities such as dredging or beach creation has historically occurred. Restoration of habitat affected by recreational modification (e.g. non-natural sandy beaches), dredging and channelization (e.g. for marinas) is possible though restoration of these habitat types is difficult and involves all levels of government. Restoration initiatives specifically for the Rocky Mountain Ridged Mussel will likely be a component of larger-scale watershed restoration projects. For example, the *Okanagan River Restoration Initiative* is a project to re-meander a section of the Okanagan River just north of Oliver. The project involves widening a section of the Okanagan River and increasing the flood plain area, improving riparian and aquatic habitat within this section (Matthews pers. comm. 2008). There is the possibility of translocating live mussels to this area, or (once the host fish is confirmed) translocating fish with glochidia to this area with the goal of establishing a population. The idea of translocating Rocky Mountain Ridged Mussels to this area needs further research and a decision analysis. In 2006/07 this area was surveyed for a number of species, including the Rocky Mountain Ridged Mussel with no mussels or shells found (Matthews pers. comm. 2008). Yearly monitoring of this site will ideally detect new mussels that may establish within the restored river section.

3. IMPLEMENTATION SCHEDULE

A single species approach is currently recommended, however management actions for the Rocky Mountain Ridged Mussel will also benefit additional aquatic species. An ecosystem-based approach may occur in the longer term, specifically if additional freshwater molluscs are listed. Incorporating management provisions into municipal, regional and protected areas management plans will further increase the conservation success of this species.

DFO encourages other agencies and organizations to participate in the conservation of the Rocky Mountain Ridged Mussel through the implementation of this management plan. Table 3 summarizes those actions that are recommended to support the management goals and objectives. Activities implemented by DFO will be subject to the availability of funding and other required resources. DFO will lead the research activity of creating a list of knowledge gaps, resources needed to address gaps, approaches to filling knowledge gaps, and partners for implementing research that fills knowledge gaps; plus, the monitoring activity of implementing inventory and monitoring protocols throughout the Okanagan watershed. Where appropriate, partnerships with specific organizations and sectors will provide the necessary expertise and capacity to carry out the listed action, subject to their agency's priorities and budgetary constraints. Future updates of the management plan will capture actions that have been undertaken.

Table 3: Implementation schedule for the Rocky Mountain Ridged Mussel. For further descriptions, see Sections: 2.3 for Actions, 2.2 for Objectives and 1.5.2 for Threats.

Action	Objective	Priority	Threat or Concerns Addressed	Time-line
Broad Strategy: Protection				
Apply and monitor existing legislation, guidelines and best management practices.	3	high	1) foreshore/riparian development; 2) historic riverbed and waterbody channelization; 3) hydrograph modification and regulation; 4) aquatic introduced species; 5) host species availability; 6) watershed land-use related pollution; 7) disturbance or direct harm	On-going
Broad Strategy: Management				
Integrate Rocky Mountain Ridged Mussels into federal, provincial, regional, municipal planning documents and guidelines as we learn more about the species.	4	high	1) foreshore/riparian development; 2) historic riverbed and waterbody channelization; 3) hydrograph modification and regulation; 4) aquatic introduced species; 5) host species availability; 6) watershed land-use	On-going

			related pollution; 7) disturbance or direct harm	
Broad Strategy: Research				
Draft an inventory schedule for watersheds with unconfirmed records of the Rocky Mountain Ridged Mussel (Kootenay, Columbia, Similkameen and southern Vancouver Island)	1	high	1) foreshore/ riparian development; 2) historic riverbed and waterbody channelization; 3) hydrograph modification and regulation; 4) aquatic introduced species; 5) host species availability; 6) watershed land-use related pollution; 7) disturbance or direct harm	2010
Create a list of knowledge gaps, resources needed to address gaps, approaches to filling knowledge gaps; and partners for implementing research that fills knowledge gaps.	1	high		2010
Build relationships with academic institutions, and raise awareness regarding research opportunities	1	moderate		On-going
Build international relationships, particularly with U.S. biologists and resource professionals working on the Rocky Mountain Ridged Mussel and mollusc conservation.	1	moderate		On-going
Broad Strategy: Monitoring and Assessment				
Continue to use and improve upon the inventory guidelines established for freshwater molluscs (e.g. FIDS guidelines) and B.C. Conservation Data Centre reporting	1	high	1) foreshore/ riparian development; 2) historic riverbed and waterbody channelization; 3) hydrograph modification and regulation; 4) aquatic	On-going

guidelines			introduced species; 5) host species availability; 6) watershed land-use related pollution; 7) disturbance or direct harm	
Complete geographic information systems mapping exercise that defines potential habitat for the Rocky Mountain Ridged Mussel in the Okanagan watershed	2	high		2010
Draft an inventory and monitoring schedule for the Okanagan watershed (e.g. using bathymetric maps, aerial photos, etc.).	2	high		2010 2010
Refine standardized protocol for mollusc inventory, habitat and threat information collection	2	high		On-going
Implement inventory and monitoring protocols throughout the Okanagan watershed.	2	high		2015
Broad Strategy: Outreach and Communication				
Continue to distribute information to dive shops, marinas, government (all levels) and resource professionals.	3	high	1) foreshore/riparian development; 4) aquatic introduced species; 5) host species availability; 6) watershed land-use related pollution; 7) disturbance or direct harm	On-going
Extend communication and distribution of the Large Lakes Protocol to public.	3	high		On-going
Develop and distribute educational materials for the Rocky Mountain Ridged Mussel, highlighting the importance and ecological function of freshwater molluscs, as indicators of water health.	3	high		2010
Modify and make accessible habitat best	3	high		2012

management practices to include Rocky Mountain Ridged Mussel habitats adjacent to private lakeshore residences and businesses.				
Provide training or information materials to resource professionals working in or near Rocky Mountain Ridged Mussel habitats.	3	high		2011
Develop and initiate a comprehensive reporting system for sightings of The Rocky Mountain Ridged Mussel in conjunction with fishing licenses and recreational sport fishery programs in the Okanagan River watershed.	3	high		2015
Work with local stewardship groups to contact landowners with property on lakeshores adjacent to optimal Rocky Mountain Ridged Mussel habitat that is both occupied (mussels present) and unoccupied (potential restoration habitat).	3	high		2015
Work with local stewardship groups to develop infrastructure, best management practises guidelines and explore other approaches that limit agricultural and private property wastewater runoff. These initiatives could be completed in conjunction with actions for other species at risk.	3	high	6) watershed land-use related pollution	2015

Broad Strategy: Restoration				
Consider Rocky Mountain Ridged Mussels in watershed scale restoration projects.	1, 3	low	1) foreshore/ riparian development; 2) historic riverbed and waterbody channelization; 3) hydrograph modification and regulation; 5) host species availability 6) watershed land-use related pollution	On-going

4. ASSOCIATED PLANS

The Rocky Mountain Ridged Mussel is scheduled for re-assessment by the COSEWIC mollusc sub-committee April 2010.

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Appendix 1: Species Similar to the Rocky Mountain Ridged Mussel

Figure 10: California Floater shell, similar in size and shape to the Rocky Mountain Ridged Mussel but lacking the lateral ridge running parallel to the anterior margin of the shell. Photo J. Heron.

Figure 11: Western Floater has a less prominent lateral line, and a smooth thin shell. Photo J. Heron.

Figure 12: Western Pearlshell. Note the concavity of the outer edge of the shell, (more prominent in older specimens). These specimens are from Ashton creek east of Enderby and north of Armstrong, B.C. Photo L. Gelling.

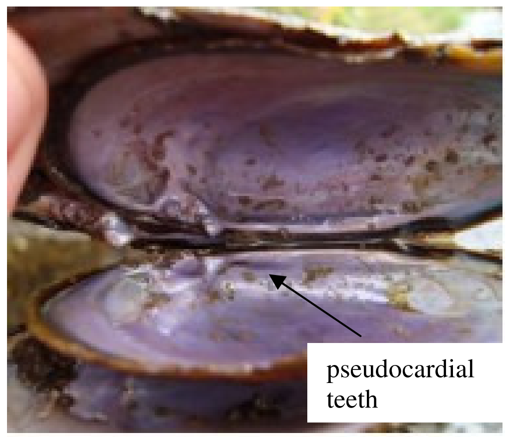

Figure 13: Inside of Western Pearlshell. Note the purplish nacre and the large pseudocardial teeth. Photo J. Heron.

Appendix 2: Occurrences of the Rocky Mountain Ridged Mussel (B.C Conservation Data Centre, 2009)

Figure 9 Map Number	Date	Location Name	11U Easting	11U Northing	Live Mussel or Shells	Currency
1	2004-07	Okanagan Lake; Summerland - Illahie Beach RV Park	308920	5495715	shells	Recent
2	15/08/2005	Okanagan Lake; Summerland - Illahie Beach RV Park	308990	5495735	live	Recent
3	24/03/2006	Okanagan Lake; Illahie Beach	308990	5495735	shells	Recent
4	2005 - summer	Okanagan Lake; Summerland dog beach	308545	5498380	shells	Recent
5	27/03/2006	Okanagan Lake, Summerland "Peach Orchard Beach" (aka Dog Beach)	308545	5498380	shells	Recent
6	24/03/2006	Okanagan Lake; Summerland dog beach	308545	5498380	live	Recent
7	28/06/2007	Okanagan Lake; Summerland Dog Beach	308545	5498380	live	Recent
8	10/07/2007	Okanagan Lake; 3 Mile Point Dog Beach	313704	5490386	live	Recent
9	27/03/2006	Okanagan Lake, Kinsmen Regional Park, Summerland	308439	5497491	live	Recent
10	01/06/2006	Okanagan Lake, Kinsmen Regional Park, Summerland	308439	5497491	live	Recent
11	13/07/2006	Okanagan Lake, Kinsmen Regional Park, Summerland	308439	5497491	live	Recent
12	27/03/2006	Okanagan Lake, "Crescent Beach", Summerland	307623	5500290	live	Recent
13	27/03/2006	Okanagan Lake, "Houseboat Beach", Summerland	307932	5499327	live	Recent
14	29/09/2008	Okanagan Lake, "Summerland Waterfront Resort"	308352	5497727	shells	Recent

Figure 9 Map Number	Date	Location Name	11U Easting	11U Northing	Live Mussel or Shells	Currency
15	20/08/2008	Okanagan Lake, "Mansion Site" (approx. 300m north of "Houseboat Beach"), Summerland	308052	5499589	live	Recent
16	1906-03	Penticton; "Okanagan River where it leaves Okanagan Lake	310867	5486584	shells	Historical
17	09/10/2005	Penticton; north of the yacht club (south end of Okanagan Lake, east side)	313190	5487308	shells	Recent
18	16/07/2006	3 Mile Beach , east side of Okanagan Lake, north of Penticton	313744	5490359	shells	Recent
19	24/07/2006	3 Mile Beach , east side of Okanagan Lake, north of Penticton	313798	5490273	live	Recent
20	08/04/2006	Penticton; north of the yacht club (south end of OK Lake, east side)	313345	5488168	shells	Recent
21	08/04/2006	Penticton; north of the yacht club (south end of OK Lake, east side)	313351	5488188	shells	Recent
22	09/08/1991	Skaha Lake, Penticton. 1.12 km south of intersection of Brantford Ave. and Lakeside Road	312883	5479739	shells	Historical
23	16/08/2005	Skaha Lake, Penticton. About 1.3 km south of intersection of Brantford Ave. and Lakeside Road (pulled off road)	313084	5478972	shells	Recent
24	11/07/2006	Skaha Lake; East side off highway	313311	5476514	shells	Recent
25	07/07/2007	Skaha Lake; H. Richardson's house, Okanagan Falls	312619	5470413	shells	Recent
26	19/07/2008	Skaha Lake; south end, Kettle Valley Railway	312645	5470756	live	Recent
27	19/07/2008	Skaha Lake; south end, Kettle Valley Railway	312574	5471161	live	Recent

Figure 9 Map Number	Date	Location Name	11U Easting	11U Northing	Live Mussel or Shells	Currency
28	19/08/1960	Okanagan Falls	312514	5468538	shells	Historical
29	20/08/1960	Okanagan Falls	312514	5468538	shells	Historical
30	12/06/1963	Okanagan Falls; Okanagan Falls Park	312514	5468538	shells	Historical
31	19/07/2008	Okanagan River, south of Skaha Lake	312555	5469344	live	Recent
32	16/08/2005	Okanagan River (south of Skaha Lk.) below 1st dam south of Prov. Park at access area	312546	5468301	shells	Recent
33	27/06/2007	Okanagan River (south of Skaha Lk.) below 1st dam south of Prov. Park at access area	312546	5468301	live	Recent
34	16/08/2005	Okanagan River (south of Skaha Lk.), below 2nd dam south of Prov. Park at access area	313442	5466525	shells	Recent
35	06/08/1972	Vaseux Lake 13.6 km N of Oliver at Public Beach	315758	5464029	live	Historical
36	16/08/2005	Vaseux Lake (south end of Summit Drive); public access area from road at S end of lake	316307	5460923	shells	Recent
37	11/07/2006	Vaseux Lake Provincial Park	316057	5463622	live	Recent
38	07/07/2007	Vaseux Lake Provincial Park	316052	5463621	live	Recent
39	17/08/2005	Okanagan River; approx. 2km south of Gallagher Lake; access at bridge	315004	5456140	shells	Recent
40	02/08/2002	Park Rill Creek, within the city limits of Oliver.	313825	5454579	shells	Historical
41	04/10/1983	Half way between Oliver and Osoyoos Lake entrance	312024	5445043	live	Historical
42	27/10/1982	Half way between Oliver and Osoyoos Lake entrance	312024	5445043	live	Historical
43	17/08/2005	400m south of Road 22 from bridge	315229	5440060	shells	Recent

Figure 9 Map Number	Date	Location Name	11U Easting	11U Northing	Live Mussel or Shells	Currency
44	07/07/2007	Okanagan River (upstream of Road 22 bridge)	314668	5440748	live	Recent
45	17/08/2005	Road 18 Bridge	312034	5444925	shells	Recent
46	28/10/1982	Okanagan River; 1.5km upstream from entrance to Osoyoos Lake	315170	5440141	live	Historical
47	04/10/1983	Okanagan River; 1.5km upstream from entrance to Osoyoos Lake	315170	5440141	live	Historical
48	16/08/1990	Osoyoos Lake, N. side of Haynes Point Provincial Park	320766	5432175	shells	Historical
49	17/08/2005	Osoyoos Lake, N. side of Haynes Point Provincial Park	320766	5432175	shells	Recent
50	27/03/2008	Okanagan Lake; Vernon, Beachcomber Bay	330115	5568363	shells	Recent
51	27/03/2008	Okanagan Lake; Vernon, Kennedy Lane Beach	331455	5568703	shells	Recent
52	30/10/2008	Okanagan Lake; Vernon, Kin Beach	332466	5569003	shells	Recent

Appendix 3: Glossary

Ambleminae	subfamily of mussels, most of which have a life stage called glochidia that infect the gills of a host fish in order to complete their life cycle.
anoxia	a water system containing low dissolved oxygen content.
benthic	"the bottom of a river, lake, or ocean where the water meets the surface of the accumulated sediments" (U.S. Fish and Wildlife Service 2008).
bivalves	molluscs (mostly aquatic) with two-part symmetrical shells held together along a hinge line.
blue-listed	"Includes any ecological community, and indigenous species and subspecies considered to be of special concern (formerly vulnerable) in British Columbia. Elements are of special concern because of characteristics that make them particularly sensitive to human activities or natural events. Blue-listed elements are at risk, but are not Extirpated, Endangered or Threatened" (B.C. Conservation Data Centre, 2009).
bradytictic	spawning takes place in summer; glochidia overwinter in females and are expelled the following spring.
commensalic	a type of symbiosis where two (or more) organisms from different species live in close proximity to one another, in which one member is unaffected by the relationship and the other benefits from it.
confirmed host fish	laboratory rearing tests have confirmed glochidia of a given mussel species attach, grow, drop off and successfully complete their life cycle using a specific host fish species.
conglutinate	"a number of glochidia bound together with mucus" (U.S. Fish and Wildlife Service, 2008).
G3	"globally vulnerable; At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors" (NatureServe, 2009).
genus	taxonomic grouping containing one or more species
glochidia	"term for freshwater mussel larvae that possess little or no automotive abilities that are ready to be released from the female mussel and usually attach to a vertebrate host for continued life

	cycle development" (U.S. Fish and Wildlife Service 2008).
hypoxia	A water system containing high dissolved oxygen content
littoral	The light zone of the aquatic habitat within the water, where light reaches the bottom
location	"a geographically distinct area where a group of individuals of a species is (or has been) found. The total population of a species may comprise a number of sites. Dispersal between sites is impossible or very rare. A single threatening event can rapidly affect all individuals in a site. Where a taxon is affected by more than one threatening event, location should be defined by considering the most serious plausible threat. (Source: adapted from IUCN 2001)" (COSEWIC, 2009).
microorganisms	Small microscopic organism at the base of many food chains
mucilaginous	moist jelly-like substance/coating that protects against dehydration
nacre	shiny sheet-like shell layers inside of a mollusc shell
native species	"a wild species that occurs in Canada naturally, or that has expanded its range into Canada without human intervention from a region where it naturally occurred, has produced viable populations, and has persisted in Canada for at least 50 years" (COSEWIC, 2008).
parasitic or parasite	an organism that grows, feeds, and is sheltered on or in a different organism (host) while contributing nothing to the survival of the host
periostracum	thin organic coating or layer on the outside of the shell, is yellowish brown to blackish brown, the outside layer or covering of the shell.
planktonic	"exhibiting movements characteristic of plankton" (U.S. Fish and Wildlife Service, 2008).
red-listed	"Includes any ecological community, and indigenous species and subspecies that is extirpated, endangered, or threatened in British Columbia. Extirpated elements no longer exist in the wild in British Columbia, but do occur elsewhere. Endangered elements are facing imminent extirpation or extinction. Threatened elements are likely to become endangered if limiting factors are not reversed. Red-listed species and sub-species may be legally designated as, or may be considered candidates for legal designation as Extirpated, Endangered or Threatened under the *Wildlife Act* (see

	http://www.env.gov.B.C..ca/wld/faq.htm#2). Not all Red-listed taxa will necessarily become formally designated. Placing taxa on these lists flags them as being at risk and requiring investigation" (B.C. Conservation Data Centre, 2009)
S1	"Critically Imperilled; critically imperilled in the nation or state/province because of extreme rarity (often 5 or fewer occurrences) or because of some factor(s) such as very steep declines making it especially vulnerable to extirpation from the state/province" (NatureServe, 2009).
Special concern	"a wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats (COSEWIC, 2008).
stolon	runners that creep along the lake bed
pseudocardinal	the triangular, often serrated, teeth located on the anterior-dorsal part of the shell. Structures resembling teeth used in some species to hold the shell together.
tachytictic	spawning takes place in spring, and glochidia are expelled during summer
taxonomically	closely related biologically to another species.
umbo	"the inflated dorsal part of the shell; also called the beak" (U.S. Fish and Wildlife Service, 2008).
unconfirmed host fish	host fish that has glochidia embedded within its gills although it is unknown if the glochidia mature and are successful in establishing as adult mussels.
Unionids	"refers to freshwater mussels in the order Unionoida. "Unio" is latin for pearls" (U.S. Fish and Wildlife Service, 2008).

Appendix 4: Photograph credits

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Appendix 5: Record of Cooperation and Consultation

The Rocky Mountain Ridged Mussel is listed as a species of ‘special concern’ on Schedule 1 of the Species at Risk Act (SARA). As an aquatic species, the Rocky Mountain Ridged Mussel falls under federal jurisdiction, and is managed by DFO 200 - 401 Burrard Street, Vancouver, B.C., V6C 3S4.

DFO and the Province of British Columbia cooperated on the development of this draft document through a management team comprised of experts. Processes for coordination and consultation between the federal and British Columbian governments on management and protection of species at risk are outlined in the *Canada-B.C. Agreement on Species at Risk* (2005)

A draft version of the management plan was posted to the DFO Pacific Region website for public comment from December 21, 2009 - January 22, 2010; an initial draft (December 2009) of the management plan along with background information was provided. These consultations were web-based, however mail-outs requesting feedback were also sent to First Nations and municipal governments occurring within the distributional range of the species. No feedback was received from First Nations, municipal governments, or from submissions via the DFO Pacific Region website.