RECOVERY POTENTIAL ASSESSMENT FOR ROCKY MOUNTAIN RIDGED MUSSEL (*GONIDEA ANGULATA*) IN BRITISH COLUMBIA

Figure 1. Gonidea angulata at Dog Beach, Okanagan Lake in Summerland, July 2009. Note the prominent posterior ridge. (Photo by L. Stanton).

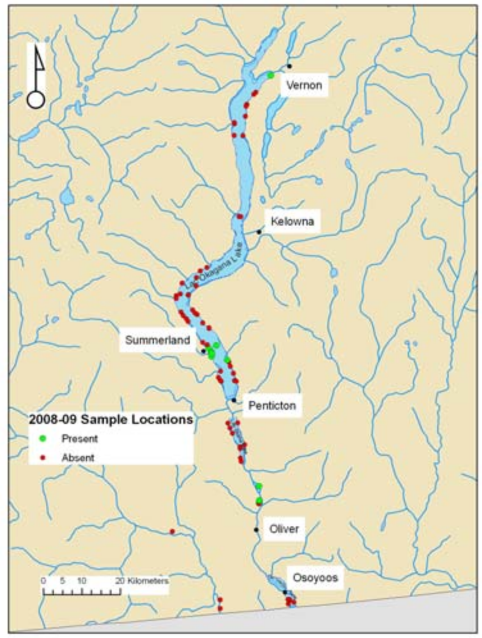

Figure 2. Gonidea angulata survey locations conducted from 2008-2009 within the Okanagan Basin.

Context :

The Rocky Mountain ridged mussel (RMRM, Gonidea angulata) is a freshwater bivalve mollusc that reaches the northern extent of its global distribution in southern British Columbia. In May 2010 the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed this species as Endangered. Current Fisheries and Oceans Canada (DFO) practice is to undertake a recovery potential assessment when a species is assessed as Endangered or Threatened. RMRM is presently restricted to the Okanagan Basin with small aggregations present in the northeast and southwest areas of Okanagan Lake, in addition to a few individuals encountered in Vaseaux Lake and the Okanagan River. Potential or known threats and their impacts to habitat such as channelization of the Okanagan River, dams and weirs, development of shoreline and littoral zones, pollutants, introduced species such as Eurasian watermilfoil and dreissenid mussels, are evaluated and mitigation measures were recommended. Recommendations for future research are provided in an attempt to fill knowledge gaps and to meet recovery objectives to sustain viable populations and prevent extirpation of the Rocky Mountain ridged mussel in Canada.

*This Science Advisory Report has resulted from a Fisheries and Oceans Canada, Canadian Science Advisory Secretariat regional advisory meeting of February 25, 2011 on Recovery Potential Assessment (RPA) of Rocky Mountain Ridged Mussel (*Gonidea Angulata*) in British Columbia. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.*

SUMMARY

- The Rocky Mountain Ridged Mussel (RMRM) was originally designated as a species of special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and under the Canadian Species at Risk Act (*SARA*) in 2003. In 2010, it was re-assessed by COSEWIC, and based on recent population trends, identified past impacts, ongoing and future potential threats, it was designated Endangered.
- The completion of a Recovery Potential Assessment (RPA) is required to inform the SARA listing decision, and provides the scientific background, identification of threats and probability of recovery of a species.
- Data from recent surveys show that RMRM is sporadically distributed and limited to the Okanagan Basin. In addition, limited information on the population and size structure, with little evidence of recruitment, indicates the species is in decline and at risk of extirpation.
- There is very little known about the specific life history parameters for RMRM, or its ecosystem role, specific micro-habitat requirements and preferences, confirmed glochidia fish host species and limiting factors to recruitment.
- Identified habitat pressures and threats include: channelization of the Okanagan River; dams and weirs; development of shoreline and littoral zone; pollutants; other introduced species, and the potential threat of dreissenid mussels.
- Ongoing or planned mitigation measures include: improvement of water quality; managing Okanagan Lake levels, and possibly the Okanagan River Restoration Initiative.
- Protocols and guidelines are needed to assess the impacts of continuing habitat pressures for consistent protection of the functional habitat characteristics of mussel habitat as well as potential glochidia host fish habitat.
- Allowable harm activities provide the required biological information required to increase productivity and survival should be restricted to areas of greatest abundance at a level that is comparable to natural mortality (which needs to be determined).
- Expected population trajectories associated with specific scenarios are outlined including extirpation, stabilizing existing populations, and expanding populations to previously occupied habitats in the Okanagan Basin.
- Recommendations are made for research activities to provide specific biological information needed for a sound management plan to reverse the decline and ensure the persistence of stable self-sustaining RMRM populations.

BACKGROUND

Distribution and Biology

The Rocky Mountain Ridged Mussel, *Gonidea angulata* (I. Lea, 1838), is a freshwater bivalve mollusc in the family Unionidae. It is taxonomically and morphologically unique; the only extant species in this genus (Graf 2002). It is a large, thick shelled trapezoidal shaped mussel with a sharp and prominent posterior ridge (Clarke 1981) (Figure 1).

Historically, RMRM ranged from southern British Columbia to southern California and eastward to Idaho and Nevada. Once common throughout California and abundant in the large tributaries of the Snake and Columbia River in Washington, Idaho and Oregon, there is evidence of extirpation from some regions and evidence of reduced abundance throughout its range (Taylor 1981).

All freshwater mussels of the order Unionidae possess a unique life history trait of having an obligate parasitic glochidia larval stage, during which they depend upon the availability of a suitable fish host to complete their reproductive cycle. Unconfirmed glochidia fish host species from other areas include two species present in the Okanagan Basin. Only preliminary studies on the reproductive timing of RMRM populations have been conducted within their Canadian range. The loss, decline or displacement of natural fish host populations may adversely affect freshwater mussel populations.

Ecosystem Considerations

Healthy mussel communities occur as multispecies assemblages in which positive species interactions are likely very important. The previous littoral mussel community structure that existed before developmental pressures is unknown.

The general ecosystem role of benthic bivalves is to cycle nutrients between the water column and sediments, and act as an ecosystem engineer by being an important structural component in the sediments. The significant loss of healthy mussel communities and the invasion of exotic species may result in large alterations to ecosystem processes. While restoration and recovery of single imperilled species is to be commended, it may not be very effective at maintaining community and ecosystem function.

ASSESSMENT

Current species status

Range and number of populations

The current observed range of RMRM in southern British Columbia is exclusively within the Okanagan River watershed from north Okanagan Lake near Vernon and south to Osoyoos Lake (Figure 2). The highest concentrations are found in Okanagan Lake off Summerland, BC. Few mussels have been observed outside this described area, most notably small aggregations were discovered on Okanagan Lake near Vernon, Okanagan River and Vaseaux Lake based on the most recent surveys in 2008 and 2009 (Figure 2). Evidence from recent surveys suggests their range may have decreased from previous years.

Recent species trajectory

Evidence from past and recent qualitative surveys suggests their range and abundance may have decreased from previous years. There is very little evidence of recruitment throughout the Okanagan Basin, but there are considerable accumulations of large adult dead shells. However, targeted surveys for juvenile mussels have not been undertaken.

Life history parameters

Limited information is available on specific life history parameters and recruitment for RMRM and for many freshwater mussels in general. The lifespan of RMRM is unconfirmed, but there are reports of maximum ages of 22-24 and 60 years. Unionids exhibit extremely low juvenile survivorship and high adult survivorship.

Habitat requirements and habitat use patterns

RMRM are found in shallow oligotrophic waters and in a variety of well-oxygenated substrate types and constant flow water velocities (Clarke 1981; COSEWIC 2003). In Canada, RMRM are more commonly found in lakes, likely due to severely degraded river habitats in the native range (COSEWIC 2010).

Population and distribution targets

With the apparent declining freshwater mussel trends in North America, and the lack of specific biological information for RMRM, it is unrealistic to expect full recovery to a status of not at risk. RMRM appear to be declining relict population(s) at the northern edge of its range, and the prevention of RMRM extirpation from the Okanagan Basin could be the primary target, followed by a significant reduction in the risk of extirpation. To achieve these targets a three step process is recommended:

1. conserve the structure and abundance of known RMRM aggregations and enhanced protection of the habitat of the existing population(s);
2. ensure continued sustainability of RMRM aggregations by protecting/enhancing the ability of successful larval settlement and recruitment to reproductive adult stages; and
3. re-establish self-sustaining RMRM sub-populations/aggregations where only dead shells have been collected, or increase the abundance where currently only small live aggregations currently occur.

The following biological information is needed in order to develop a biologically based management plan in support of preventing:

1. Evaluation of glochidia dispersal by host fish, as the fish host is unknown in the Okanagan Basin;
2. Determination of minimum viable population size;
3. Assessment of predator pressure and assessment of sources of mortality;
4. Assessment of microhabitat features that support RMRM; and,
5. Confirmation of successful recruitment using appropriate juvenile surveys.

Expected population trajectories and time to recover

Using the COSEWIC policy of three generations to determine status and trends, with estimated generation time of 15 years and reported maximum age of 22-24 years, evidence of stable naturally reproducing populations or recovery to previously existing self-sustaining populations in the Okanagan Basin would be expected to take 50-70 years.

Scope for Management to Facilitate Recovery

Probability that the recovery targets can be achieved

In the absence of biological productivity, determining the probability of success is dependent on the elimination or mitigation of limiting factors and threats.

Magnitude of each major potential source of mortality

Channelization of the Okanagan River

Channelizing the Okanagan River reduced the total length by one third, with only 4 kilometres of the original 61 kilometres remaining in a natural state, resulting in the removal of 93% of natural river habitat which resulted in a steeper channel (Rae 2005). The distribution and abundance of RMRM before channelization and dredging is unknown. Assuming they occurred in the previously undisturbed sections, channelizing and dredging would have had severe detrimental impacts both on the functional characteristics of suitable mussel habitat and on any potential glochidia fish host habitat. In addition building dykes resulted in the removal of an estimated 85% of riparian vegetation (Rae 2005), resulting in elevated water temperatures that may be beyond the maximum tolerance for native fishes and mussels.

Dams and Weirs

There are three dams on the Canadian portion of the Okanagan River, all with fish ladders that are not in use because of historical concerns about introduced species. One of the dams, McIntyre, was retrofitted in 2009 with gates that allowed water to flow over them to provide for fish passage (in particular sockeye, and to improve downstream migration of salmonids). The retrofit has been successful, with both sockeye and Chinook found to have utilized the habitat upstream to the next barrier at Skaha dam. Seventeen vertical drop structures or weirs were installed to reduce water velocities in the steeper modified river channel (Rae 2005). There are also nine large dams on the Columbia River downstream of the Okanagan River confluence which blocked the migration of some anadromous fish species that had been present according to Traditional Ecological Knowledge. The role of these fish species as glochidia fish hosts is unknown, but their contribution to in-stream organic nutrient input may have been an important factor affecting mussel growth and reproductive success. Depending on the structure and operations of the flow control structure, removing the ability of potential host fish to bypass barriers may result in too little habitat to support viable glochidia host fish populations and severely restrict the dispersal of glochidia past the barriers.

Flow regulation by dams and weirs can be advantageous and/or disadvantageous to mussels. Because most of the RMRM occur in lake habitats in the Okanagan Basin, controlling the level of Okanagan Lake to protect the existing populations of RMRM is the most obvious advantage of flow control. The disadvantages often seen as a result of flow control and flow control structures on mussel habitat include: fractionating riverine habitats; detrimental impacts on depositional processes; and detrimental changes to hydrograph.

Development of Shoreline and Littoral Zones

There has been considerable alteration and loss of natural shoreline features and the littoral zone which likely impacted a portion of RMRM habitats. Agriculture developments may contribute runoff and/or groundwater effluent containing fertilizers, herbicides and pesticides to the littoral zone. Nutrient input from septic fields may contribute to localized littoral zone enrichment beyond the tolerable range of mussels. Altering the shoreline by bank armouring with retaining walls may change the energy dissipation characteristics of breaking waves to the detriment of mussel habitat. Replacement of natural riparian vegetation with lawns and sand may increase littoral zone temperatures and increase ammonia and nitrogen loading. Adding sand to the shoreline may result in washouts, altering mussel habitats by infilling interstitial spaces or smothering resident mussels. Installation of geothermal heating pipes in the littoral zone may have detrimental habitat impacts depending on the method of installation, changes on localized temperature shifts and changes in near-bottom hydraulics. However, the largest remaining RMRM aggregations in the Okanagan Basin are close to where sand has been dumped and spread. Changes in the abundance and distribution of mussels from historic levels at this site are unknown. In the Okanagan Region, a number of activities occur which are potentially detrimental to mussel habitat, and almost all require permitting under the *B.C. Water Act*. However, a recent compliance study of developed sites on Okanagan Lake and Skaha Lake showed non-compliance was almost 100%. In addition, an estimate of Okanagan Lake shoreline alterations in the mid-1990s showed that 80% of the southwestern and northern shores had been altered, mainly by house, road and dock construction (Rae 2005), which is in the area of greatest RMRM concentration in past surveys.

Pollutants

Development pressures may also have contributed to mussel habitat degradation by chemical pathways. There are three mechanisms by which pollutants may impact mussels:

- ammonia;
- nutrient enrichment and compounds with a high affinity for suspended particles or sediments (e.g. metals, organochlorines, polychlorinated biphenyls and polyaromatic hydrocarbons); and
- endocrine disruptors (e.g. pesticides, pharmaceuticals, tributyl tin, anti-fouling paints and residuals from detergents (Strayer 2008).

Other Introduced Species

Fourteen introduced fish species live in Okanagan Basin lakes and seven introduced species live in sections of the Okanagan River. The potential competitive pressure of introduced fish species on native glochidia host fish is unknown.

First introduced to Okanagan Lake as a food source for Kokanee salmon, *Mysis relicta*, a small freshwater shrimp, was found to compete with fish for food. They have been directly linked to the decline of Kokanee salmon (Rae 2005). The impact of food chain alteration resulting in the decline of fish and change in nutrient levels is unknown on RMRM.

Likely the best known and most highly visible introduced species, Eurasian watermilfoil (*Myriophyllum spicatum)*, has spread in the shallow littoral zone throughout the Okanagan Basin since 1970 (Rae 2005). While milfoil proliferation may have impacts on RMRM habitat, active eradication and control programs also have potential impacts. The least obtrusive control method is harvesting by mowing from the water surface with underwater cutter blades during the summer close to peak seasonal biomass. The second method is rototilling during winter with specially designed equipment which operates at water depths up to 4.5 m to penetrate the bottom substrate displacing the roots (Okanagan Basin Water Board (OBWB, 2011). Since the inception of the milfoil program the emphasis has changed from cut harvesting to rototilling, as the latter is considered most effective (Okanagan Basin Water Board 2011). Individual mussels risk being killed or harmed if tilled, and individuals could be harmed and their habitat degraded if sediment generated in adjacent areas entered the populated sites. The Okanagan Basin Water Board (2011) undertook a limited study on rototilling and sediment dispersal due to the Province of B.C.'s concerns related to potential degradation of adjacent kokanee spawning areas. There has not been a targeted study on the impacts of rototilling on mussels.

Dreissenid mussels

While zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena rostriformis)* have not yet been detected in the Okanagan Basin, they are likely the greatest potential threat to resident RMRM. Both species of dreissenid mussels became established in Eastern North America in the 1980s and zebra mussels in particular have become one of the most widespread and abundant freshwater animals (Strayer 2008). Given the high risk potential derived from water quality parameters (Mackie 2010), the high profile of recreational boating and tourism access, as well as the failure to prevent dreissenid mussel proliferation in the U.S. despite a dedicated program (Hickey 2010), the risk of future dreissenid mussel establishment and proliferation in the Okanagan Basin is high.

Likelihood that the current quantity and quality of habitat is sufficient

The likelihood that the current quantity and quality of habitat are sufficient to allow recruitment and stability at present levels is difficult to evaluate as basic biological requirements, micro-habitat preferences, and quantifiable tolerances of RMRM are unknown.

Magnitude by which current threats to habitat have reduced habitat quantity and quality

Channelizing and dredging the Okanagan River have likely altered river habitat for RMRM with a 93% loss of natural river channel.

In Okanagan Lake, alteration of an estimated 80% of shoreline and littoral zone where mussels presently occur likely has had a major impact. Most of the Skaha Lake shoreline has been altered by road, railway or residential development. Osoyoos Lake has higher nutrient levels than either Okanagan Lake or Skaha Lake, resulting in a very productive (mesotrophic) lake with extensive algal growth (Rae 2005).

For future potential habitat losses, a risk analysis for dreissenid mussel infestation indicates the risk is high and could have catastrophic impacts as seen in other areas (Mackie 2010).

Scenarios for Mitigation and Alternative to Activities

Inventory of mitigation measures

Improvement of water quality has resulted from the operation of sewage treatment plants to remove most of the phosphorous from effluents (Rae 2005), assisting in conserving the oligotrophic characteristics of Okanagan Lake in spite of development pressures surrounding Okanagan Lake.

The depth of the shallowest mussels in Lake Okanagan or Okanagan River segments could be converted to stage height, and the potential for protection of the existing mussel beds from dewatering and scour could be flagged within the Fish Water Management Tool (a computer model that incorporates all the available information on impacts from dam operation on specific aquatic biota).

The Province of B.C. has the Okanagan Large Lakes Foreshore Protocol (OLLFP) that provides foreshore sensitivity maps based upon Kokanee, RMRM and rare plants, risk ratings for specific development activities, and preferred procedures and practices. The Protocol applies to Mabel, Sugar, Okanagan, Kalamalka, Wood, Skaha and Osoyoos and Christina lakes and is used as guidance for all other lakes in the Okanagan Region (e.g. Vaseux Lake). Known areas of RMRM are identified as Red, denoting a higher sensitivity. The OLLFP defines what activities are referred for agency review, what are considered lower risk, or that require specified mitigation measures, and those that are not to be referred for review by DFO and the Province. Further specifications that relate to the OLLFP are found in the *Habitat Officer's Terms and Conditions for changes in and about a stream specified by Ministry of Environment Habitat Officers, Okanagan Region.*

The detection protocol aspect of the DFO Protocol for the Detection and Relocation of Freshwater Mussel Species at Risk utilizes the detection protocol developed by Pacific Region in 2006 specifically for RMRM in the Okanagan. The relocation aspect of the DFO Protocol for the Detection and Relocation of Freshwater Mussel Species at Risk is based on Mackie *et al*. (2008). It is uncertain if the relocation protocol is effective. Early experience with moving the animals is showing it to be traumatic and risky. The Province is reviewing the protocol in 2011-2012.

The OBWB funds and operates a milfoil control program. Their rototilling currently avoids known areas populated with RMRM. They utilize the habitat sensitivity mapping information within OLLFP.

The Okanagan River Restoration Initiative (ORRI) has a phased approach to restoring natural river habitat conditions by providing access to the old river channel from a channelized portion of the lower river in the vicinity of the town of Oliver. While the focus of ORRI is to improve instream habitat for finfish, there are potential benefits to some identified functional habitat characteristics of mussels outlined by Strayer (2008).

Alternatives to human activities and threats to habitat

The compliance rate of some activities that require permitting under the *BC Water Act* is very low (COSEWIC 2010). Active enforcement of existing legislation on habitat protection measures is needed to protect mussel and glochidia host fish habitat, as well as the overall littoral zone ecology. Cumulative effects of past activities (legal or illegal) need to be considered in the permitting process. Any detection, salvage or relocation activity with mussels should be appropriate to the site conditions, and only occur at temperatures where they are active and can re-burrow in suitable substrate. Existing protocols should be evaluated in this regard.

The control and harvest of Eurasian milfoil is likely one of the most extensive on-going in-water activities in the Okanagan Basin. Specific guidelines based on the best available scientific information (as it develops) for protection of mussel habitat are recommended to ensure consistent management practices.

Prop washing within lake littoral zones may be used by residents to maintain sufficient clearance for access to private docks, which may have detrimental effects on mussel habitat and host fish habitat. Procedures and guidelines for boat channel maintenance should be reviewed for near-field and far-field potential impacts on mussels and potential glochidia fish hosts and their respective habitats.

Relying on individual approvals may result in inconsistencies with impact assessments and may not adequately consider cumulative impacts of other installations or other development pressures. Best management practices need to be developed with careful consideration of ecological impacts on littoral zone species and habitats.

Reasonable and feasible activities that could increase the productivity or survivorship parameters

In the absence of detailed biological information on RMRM to assist in developing action plans to increase productivity and reduce mortality, the alternative approach is to rely on a generalized risk management framework for habitat management (DFO 2006), habitat management guidelines for *SARA* listed species (DFO 2007), as well as derived pathways of effects models that result from the identified pressures and threats to habitats similar to that of Coker *et al.* (2010) to conserve and enhance Strayer's (2008) functional characteristics of suitable mussel habitat. Developing pathways of effects with conceptual models would greatly assist in the development of appropriate mitigation measures to increase productivity and survival. Continuing to reflect the sensitivities of the RMRM biology as we learn more about the species within the OLLFP and related Habitat Officers Terms and Conditions continues to be a useful means for delivering the risk management approach.

There is an urgent need to determine and address the limiting factors to recruitment in order to increase productivity. The potential impact of habitat pressures and present practices/uses would be clarified if limiting factors were better understood, and mitigation measures could be focused on addressing those limiting factors where possible.

There may be opportunities with river habitat restoration efforts of the ORRI for the reestablishment of riverine RMRM populations. Transplanting adult individuals from large aggregations could be considered as a means of seeding the newly restored habitat. Minimum viable population size is unknown and this could be an opportunity to consider controlled experiments. However, this option should be considered with great caution given all of the uncertainties around habitat preferences, stress from handling and risks from predation.

Allowable harm

Due to a lack of basic biological information on RMRM life history parameters, and uncertainty of the effects of potential threats, allowable harm is necessary for activities which contribute to collecting the information necessary to develop a scientifically sound plan focusing on reducing the risk of extirpation and increasing productivity and survival. Allowable harm activities should initially be restricted to areas of greatest abundance in Okanagan Lake near Summerland at a level that is comparable to natural mortality. However, natural morality has yet to be determined and further investigations are warranted. As more comprehensive information is developed, it could be considered for other areas to facilitate restoration efforts to expand the species distribution.

Expected population trajectories associated with specific scenarios

While specific information on productivity parameters for RMRM to assist in predicting population trajectories is missing, using existing information on extirpation from areas within its range in the U.S., recent declines in abundance and distribution in B.C., and the potential risks of dreissenid mussels with their documented impacts in the U.S. under different scenarios, the following population trajectories would be expected in B.C.:

1. Without a comprehensive action plan to address and manage the dreissenid mussel threat and the means to successfully implement it, the extirpation of RMRM is likely within 3-5 years after the introduction of dreissenid mussels to the Okanagan Basin.

2. With continuation of the status quo, with low compliance of existing protection measures and no efforts to determine and address the limiting factors of recruitment of existing populations, the extirpation of RMRM from the Okanagan Basin is likely within 10 years.

3. Immediate enhanced habitat protection measures at present aggregation sites to promote potential recruitment may provide age classes to replace the dwindling ageing population. Evidence of recruitment success would likely be seen in 5-10 years, and evidence of potentially stable age structures would be seen in 20-30 years. Assuming population sustainability and stability are inferred after three generations, evidence of sustainability of existing populations at Summerland and Vernon would likely be confirmed after 60-70 years. The probability of success is uncertain, as there may be other under-lying factors which are presently unknown. However, the probability of success would increase if the limiting factors to recruitment were known, and measures were undertaken to alleviate or mitigate those limiting factors. This is Step 1 of reducing the risk of extirpation outlined in Population and distribution targets.

4. Enhanced habitat protection measures at designated mussel-sensitive sites (where they have been previously seen live or where there are dead shells) and at sites where a few sporadically distributed live mussels were seen (such as 3-mile beach at Naramata) may provide age classes to replace the dwindling ageing population. Evidence of success would be in the same time frame as outlined above in (3). This is Step 2 of reducing the risk of extirpation outlined in Population and distribution targets.

5. Efforts to restore key selected and previously degraded lacustrine and riverine habitats to the functional characteristics of suitable mussel habitat (in stages, once aforementioned risks of transplants are addressed and utilizing most appropriate methodology for the site, then refinement as more information is developed) would establish populations in several areas, providing more overall stability to Okanagan Basin populations. Determining and maintaining minimal viable population size is a key requirement to re-establishing populations where they previously occurred. Evidence of success would be in the same time frame as outlined above in (3). This is Step 3 of reducing the risk of extirpation outlined in Population and distribution targets.

Parameter values for population productivity and starting mortality rates

Due to a lack of biological information for RMRM, it is not possible to estimate or predict parameter values for population productivity. However, it is possible to predict population sustainability by size structure (assuming it correlates with age structure). The present size distribution of RMRM is a narrow range of large individuals, indicating ageing populations with very little evidence of replacement by younger mussels. Evidence of a broad range of size and age classes is needed to have some confidence in the sustainability of the present populations.

Suggested research activities to address sources of uncertainty

1. Glochidia host fish determination – Detailed knowledge of fish hosts is key to a number of issues: determining limiting factors to recruitment and productivity; habitat protection, enhancement and restoration; predicting recovery trajectories; and determining

feasibility of establishing populations in previously degraded areas. Consequently, in the absence of this information, measures developed for the adequate conservation and protection of the remaining RMRM populations have a high degree of uncertainty. Future research should concentrate efforts on identifying potential fish hosts during known periods of glochidial encystment and on accurately identifying glochidia either by morphological characteristics or genetically.

2. Adult and juvenile micro-habitat preferences - Specific habitat preferences of both adult and juvenile RMRM populations need to be determined in order to successfully restore and protect this species in southern British Columbia. This basic knowledge is necessary before the translocation of mussels is considered.

3. Determination of at-depth distribution - Preliminary evidence suggests mussel populations/aggregations may exist at greater than snorkeling depths within Okanagan Lake and Vaseaux Lake. Future surveys should incorporate broad brush exploratory surveys using SCUBA diving to determine the exact distribution of RMRM within the lakes of the Okanagan Basin.

4. Genetic analysis – Genetic analyses are necessary to determine whether British Columbia populations are genetically distinct from U.S. populations as it is plausible that the southern British Columbia populations are genetically distinct given the unconfirmed differences in habitat preferences between RMRM populations in Canada and the United States (i.e., lake versus river habitats). Further, RMRM populations in southern British Columbia are small, at the northern extent of their range, and are potentially isolated from U.S populations due to barriers such as large dams, etc. which would restrict fish host movement and gene flow among populations. In addition, genetic analyses are a necessary and important prerequisite to translocating individuals thereby increasing success in the re-established habitat and preserving genetic diversity.

5. Re-establishment in restored river habitat - Once glochidia fish hosts and habitat preferences are determined, translocating small aggregations of either host fish infected with glochidia or mussels to restored areas of the Okanagan River could be considered.

6. Determination of successful recruitment - Appropriate methodologies to test for juvenile presence should be applied rigorously to confirm that recruitment really is limited or non-existent.

Sources Of Uncertainty

Detailed life history parameters required for population viability analysis are unknown. The glochidial fish host is unknown. Both of these knowledge gaps need to be filled for the development of effective management actions. Although potential threats to survival and recovery have been identified, they have not been quantified and require further study to determine the actual potential level of impact. Given the species cryptic nature, further populations could be discovered with more thorough shoreline snorkel surveys.

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