Nature Conservation 42: 19–31 (2020)
doi: 10.3897/natureconservation.42.51081
http://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Mapping Rocky Mountain ridged mussel beds with preliminary identification of overlapping Eurasian watermilfoil within the Canadian range

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Academic editor: B. Rinkevich | Received 12 February 2020 | Accepted 7 September 2020 | Published 23 September 2020

http://zoobank.org/84868E50-C1A9-4E8D-BA27-1A2C6AA5E41C

Citation: Wade J, Stephen C, Robertson C (2020) Mapping Rocky Mountain ridged mussel beds with preliminary identification of overlapping Eurasian watermilfoil within the Canadian range. Nature Conservation 42: 19–31. https://doi.org/10.3897/natureconservation.42.51081

Abstract

The Rocky Mountain ridged mussel (*Gonidea angulata*) is a bivalve species whose Canadian range is limited to the Okanagan Valley, British Columbia. In 2019, conflicts between habitat protection for the mussel and potential habitat alteration to control the invasive Eurasian watermilfoil (*Myriophyllum spicatum*) (milfoil), led to a decision to maintain the status of the mussels as Special Concern under Canada's Species at Risk Act (SARA) rather than classify it as Endangered. Milfoil control can cause direct mortality and/or burial of the mussels, but there had been no systematic study of the impacts of milfoil control on mussel beds. The purpose of this study was to address knowledge gaps by delineating known mussel beds and potential overlap with milfoil to provide information for management decisions that balance the needs of native species protection and invasive species control. Rocky Mountain ridged mussels in three reference locations were enumerated using snorkel surveys. The presence and distribution of milfoil was documented in relation to five sites within these three locations. Milfoil was encroaching on one site, causing some changes to the substrate. At other sites, the differences in the depth and distribution of the mussel and the milfoil could allow milfoil control without damaging the mussel beds. It is recommended that, before milfoil removal near known mussel beds be undertaken, a detailed site evaluation be conducted to determine potential impacts. This study suggests presumed impediments to co-managing the mussels and controlling an invasive species should not preclude classifying the mussels as Endangered and affording protections under SARA.

Keywords
Eurasian watermilfoil, western ridged mussel, conservation management, habitat, invasive species, Okanagan Valley

Introduction

Freshwater mussels (unionids) are one of the most endangered groups of animals in North America (Williams et al. 1993; DFO 2017). The Rocky Mountain ridged mussel (*Gonidea angulata*) is the only extant member of the genus Gonidea (Blevins et al. 2016). It is a bivalve mussel species whose Canadian range is limited to the Okanagan Valley, British Columbia (BC). This area marks the northernmost limit of its patchy distribution which extends south to Napa County, California and from western Oregon and Washington, east to the Snake River Basin in Idaho and south to the Humboldt basin in Nevada (Blevins et al. 2016). The distribution once included southern California, but it is now believed to be extirpated from this area (Howard 2010; Howard et al. 2015). Some Washington, Oregon and Idaho populations are believed to be in decline (Blevins et al. 2016). Comparison of the extent of occurrence (EOO) and area of watershed occupancy of these United States populations from occurrence prior to 1990 and from 1990–2015 indicates a decline in EOO by 28% and watershed area by 43% (Blevins et al. 2016).

The Rocky Mountain ridged mussel has specific habitat preferences. It can be found in both lotic and lentic streams, rivers and lakes (COSEWIC 2003; Stanton et al. 2012; Snook et al. 2019). It is a burrowing species that is typically found partially (most commonly adults) to fully (juveniles) burrowed in substrates which vary from gravel to firm mud including sand, silt or clay (COSEWIC 2003; Stanton et al. 2012). Rocky Mountain ridged mussels are normally found burrowed to at least half their length in fine substrate in water at depths less than 3 m (COSEWIC 2003). However, individuals have been reported in depths of approximately 7.5 m in Vaseux Lake (Stanton et al. 2012).

In 2003, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed this species as Special Concern largely due to its limited distribution (COSEWIC 2003). Damming of the Kootenay, Columbia and Okanagan rivers isolated the Canadian population from those further south. The Canadian population was believed to be in decline as early as 2003 (COSEWIC 2003). In 2010, COSEWIC re-assessed the species as Endangered (COSEWIC 2010). This was due to the potential threat of invasive mussel species (e.g. zebra mussel *Dreissena polymorpha* and quagga mussel *D. rostriformis bugensis*), dredging and channelling of the Okanagan River, foreshore and riparian development and other introduced invasive species, especially Eurasian watermilfoil (*Myriophyllum spicatum*). Eurasian watermilfoil is an aggressive and pervasive plant which can readily displace native vegetation. It can be found in water 1 to 10 m deep (Aiken et al. 1979); in Okanagan Lake, some plants may grow up to 8 m tall (Dunbar 2009). Both the presence of Eurasian watermilfoil and the methods used

to remove it can negatively affect the Rocky Mountain ridged mussel (COSEWIC 2010; DFO 2010; Mageroy et al. 2017).

Eurasian watermilfoil can inhibit water flow (Chambers et al. 1999) and increase siltation (Snook 2015). With increased siltation, mussels can become buried or their habitat can become unsuitable. Buried mussels cannot survive (Krueger et al. 2007). Two methods are currently used to control Eurasian watermilfoil in Okanagan Lake, rototilling in the late autumn/winter and harvesting in the summer (Dunbar 2009). Rototilling removes the roots of the plants from the substrate. The machinery can be operated in water up to 4.5 m deep. As re-growth occurs in rototilled areas, this process must be repeated for eradication. Harvesting typically occurs in areas where rototilling is not possible or where re-growth due to rototilling reaches unacceptable levels (Dunbar 2009). Plants are cut at a depth of up to 2 m below the surface when harvested. Although harvesting is reported as a faster control method, it requires the removal of the plant material and can interfere with recreational activities (Dunbar 2009). It has been shown experimentally that rototilling of Rocky Mountain ridged mussel substrate causes mortality both directly by crushing animals and indirectly by burying (Mageroy et al. 2017). Harvesting, as it is currently done, should have no direct effect on Rocky Mountain ridged mussels.

A 2019 decision by the Canadian Federal Fisheries Minister maintained the species as Special Concern rather than reclassify it as Endangered under the Species at Risk Act (SARA). The potential socio-economic impacts of limiting Eurasian watermilfoil control, which could occur if classified as Endangered under the SARA, was cited as one of the reasons for this decision (http://gazette.gc.ca/rp-pr/p2/2019/2019-08-21/html/sor-dors287-eng.html). The article also stated that additional science has become available since the COSEWIC assessment in 2010, which would challenge a classification of Endangered. The Okanagan Basin Water Board felt there was not enough evidence that the mussel could be harmed by rototilling and noted that studies on the socio-economic impacts of terminating Eurasian watermilfoil control had not been completed (Thom 2019). A local member of Parliament stated that there were "too many unanswered questions and lack of recent data to risk the unintended impact of the reclassification of the Rocky Mountain ridged mussel" (Stephen Fuhr, MP Kelowna-Lake Country in Thom 2019).

Okanagan Lake provides many benefits to local tourism and the real estate market. The goal of the Okanagan Eurasian watermilfoil control programme is to minimise environmental impacts while enhancing public enjoyment of Okanagan lakes with a cost-effective programme. No scientific evidence could be found which documented the outcomes of this programme. There has been no systematic study of the impacts of Eurasian watermilfoil control on mussel beds or on the overlap of critical mussel habitat and Eurasian watermilfoil distribution. Mageroy et al. (2017) has demonstrated experimentally that mussels can be negatively impacted (e.g. crushed and/or buried) by rototilling. Evidence-based advice regarding the interactions between this mussel species and Eurasian watermilfoil is needed to support management decisions that balance the needs of native species protection, invasive species control and economic development.

The purpose of this study was twofold. First, to map the extent of Rocky Mountain ridged mussel beds and calculate the mussel bed density at three reference locations in Okanagan Lake, British Columbia in 2019. Second, to relate mussel bed locations to a qualitative description of the presence/absence of invasive Eurasian watermilfoil in and around these reference locations.

Methods

Index sites

Rocky Mountain ridged mussel surveys have been conducted annually by Fisheries and Oceans Canada (DFO) since 2011. DFO selected three reference locations for ongoing population monitoring and included six index sites in Okanagan Lake within the locations. We used five of these index sites in this survey namely Dog Beach 1 and 2, Kinsmen Beach 1 and 2 and 3 Mile (Figure 1 and Table 1). This survey took place in August 2019.

Mussel enumeration

The enumeration methods used in this study are the same as those used since 2017 in the DFO surveys. DFO's methods have not yet been published, but one author (JW) has participated in these surveys for four years and replicated DFO's methods for this study. A surveyor's tape was placed as the baseline at or near the shore of each site, parallel to the shoreline. A leadline transect marker was pulled from the shore to depth, perpendicular to the baseline every 3 m beginning at the 0 m mark. The length of each transect varied depending on water depth and habitat suitability. Transects ended when the substrate became unsuitable for Rocky Mountain ridged mussels (e.g. excess mud) or exceeded 1.5 m depth. To confirm that transects were long enough to span the entire bed, each transect was snorkelled at least 3 m past the end of the transect to ensure no mussels were present. Transects were snorkelled from the maximum depth to as close to the baseline as possible remaining covered in water. Each transect was

Table 1. Geolocation of five index sites at three reference sites used to map and enumerate Rocky Mountain ridged mussels (*Gonidea angulata*) in Okanagan Lake, British Columbia in August 2019.

Reference Site	Index sites	Latitude / Longitude
Peach Orchard Dog Park, Summerland	Dog Beach 1	49.606999; -119.64972
	Dog Beach 2	49.607729; -119.65067
Kinsmen Beach, Summerland	Kinsmen Beach 1	49.598930; -119.65078
	Kinsmen Beach 2	49.59941; -119.65096
3 Mile Park, Penticton	3 Mile	49.538110; -119.57644

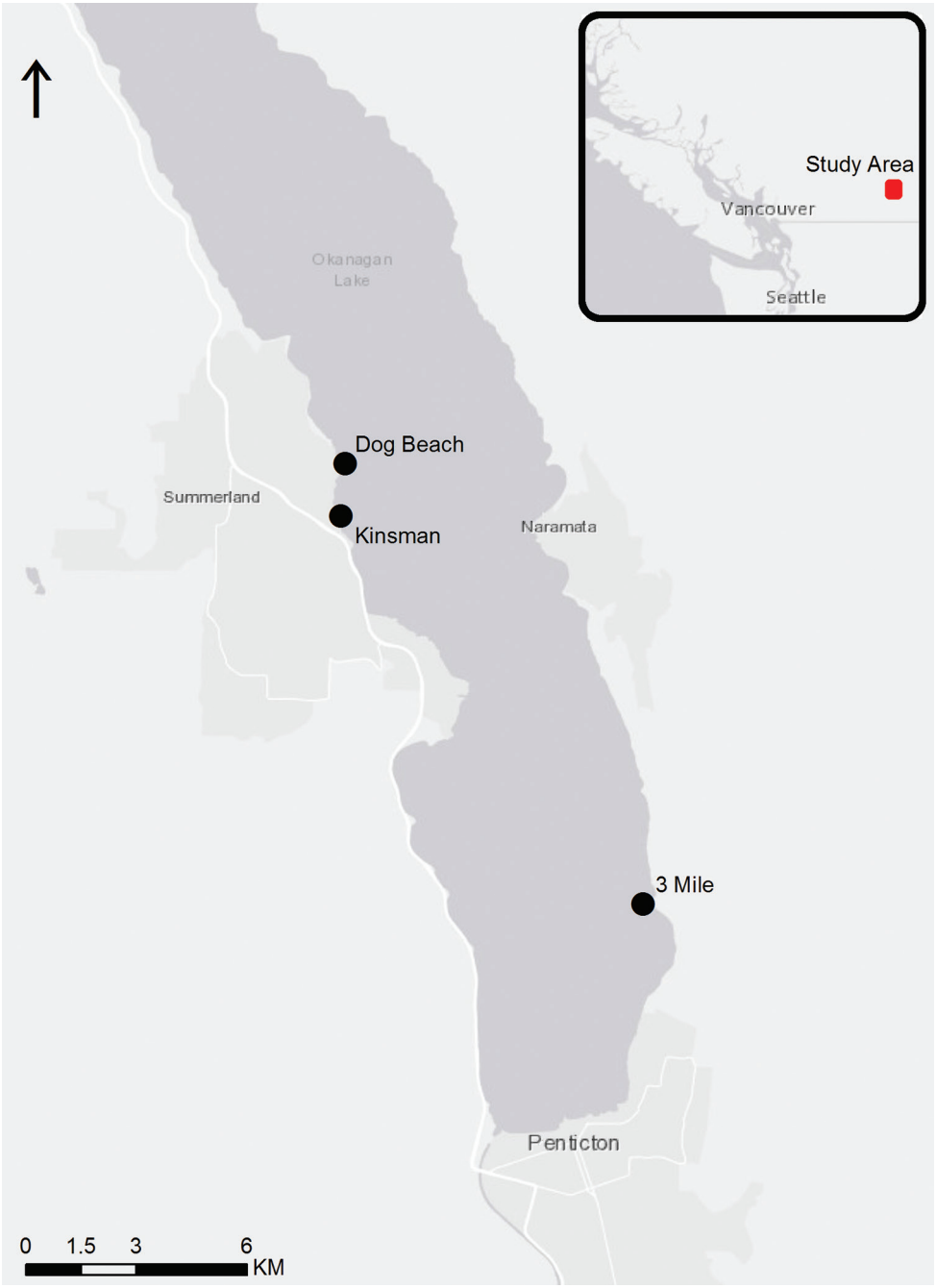

Figure 1. Location of study area and reference sites (Peach Orchard Dog Park (Dog Beach) and Kinsmen Beach in Summerland and 3 Mile near Penticton) used for Rocky Mountain ridged mussel (*Gonidea angulata*) surveys in Okanagan Lake, British Columbia in August 2019.

snorkelled holding a metre stick beside the transect line to delineate the counting area. Live mussels were counted along the transect to a width of 1 m on the right side of the transect line.

The Rocky Mountain ridged mussel burrows in the sediment with its siphon protruding. Only mussels which protruded from the substrate were counted; the substrate was not disturbed to look for mussels. No mussels were handled during any survey activities. Silt or vegetation was gently brushed aside to aid in counting. As a result of these non-invasive methods, very small mussels or those covered in heavy silt, mud, sand or gravel may not have been counted and, therefore, the abundance values are likely to be an underestimate.

Mapping

Rocky Mountain ridged mussels

For each transect, the first and last mussels counted were marked with a numbered float tied to a weight. After each index site was enumerated, the location of each marker was georeferenced using a Trimble GeoXH GPS receiver (+/- 30 cm positional accuracy) and water depth was recorded to the nearest cm. By marking the first and last mussel on the transect, an accurate delineation of the mussel bed could be mapped.

Eurasian watermilfoil (Myriophyllum spicatum)

Visual examination for the presence or absence of Eurasian watermilfoil was undertaken by snorkel surveys at all five index sites. When beds of Eurasian watermilfoil were found, the perimeter was georeferenced using the GPS to delineate the overlap with the mussel bed. When individual plants or small clusters were found, a presence/absence was recorded without quantification. Where it was not possible to map the entire extent of the plant bed because of water depth and safety concerns due to risk of entangled in Eurasian watermilfoil stems, only the perimeter closest to the mussel bed was mapped.

Analysis

Mussel bed mapping

To determine the total mussel bed area, positions of the start and end points of each baseline were determined from the GPS data. With the aid of high resolution satellite imagery, the baseline along the shore was digitised and transect starts were inferred from the length and interval spacing of 1 m. Individual transects were derived from the

starting point on the baseline, the GPS-derived positions of the floats and the recorded transect length. Transect end points were then used to digitise the outer boundary of the mussel bed. Bed area was calculated from the area of the polygon formed from digitising the position of the first float on each transect, the outer boundary and the first and last transects (buffered on one side).

Mussel bed density was calculated using the R package "survey", version 3.36 (Lumley 2004) which is a software package with functions for analysis of complex survey data. Densities were estimated separately using the function 'svyratio' (which does ratio estimation and estimates of totals, based or complex survey samples) for each index site and used to determine overall abundance from the mussel bed area (determined as above).

Results

Mussel bed density

Visibility was excellent at all index sites with the exception of the first three transects (0, 3, 6 m at the baseline) of Kinsmen Beach 1. The substrate at these three transects was too muddy and had too much Eurasian watermilfoil to accurately count the mussels. It is normally possible in areas of muddy substrate to wait for the sediment to settle before snorkelling the transect. However, at Kinsmen Beach 1, the Eurasian watermilfoil was too dense to allow visualisation of the substrate in these three transects. Half of the Kinsmen Beach 1 site has a muddy substrate, but mussel visualisation was possible after disturbed mud settled. Rocky Mountain ridged mussel bed areas and densities are presented in Table 2 and bed areas have been delineated in Figure 2.

Mussels were found in water ranging in depth from 38.1 cm to 175.3 cm (Table 2). The largest mussel bed area was delineated at the Dog Beach 1 index site (1,766.78 m^2) with the second smallest mussel bed density of 0.22 mussels/m^2. The greatest mussel bed density was found at 3 Mile (1.23 mussels/m^2). Kinsmen Beach 1 and 2 sites had similar mussel bed areas (738.84 and 619.92 m^2, respectively) as well as densities (0.86 and 0.79 mussels/m^2, respectively). Total population estimates (Table 2) were estimated to range from a low of 128.88 at Dog Beach 2 to a high of 1,668.28 at 3 Mile.

Table 2. Results of snorkel surveys to map and enumerate Rocky Mountain ridged mussels (*Gonidea angulata*) at five index sites in Okanagan Lake, British Columbia in August 2019 (s.e.= standard error).

Index site	# transects surveyed	Range of number of mussels/ transect	Depth (cm) of mussel found		Bed area (m^2)	Bed density (mussels/ m^2)	Population Estimate (s.e.)
			Nearest to shore	Furthest from shore			
Dog Beach 1	21	1–12	53.3	175.3	1,766.78	0.22	383.00 (44.35)
Dog Beach 2	18	0–8	55.9	127.0	971.44	0.13	128.88 (25.43)
Kinsmen Beach 1	16	0–37	38.1	134.6	738.84	0.86	637.90 (134.08)
Kinsmen Beach 2	12	0–27	40.6	124.5	619.92	0.79	490.80 (107.41)
3 Mile	25	2–35	43.2	175.3	1,355.15	1.23	1,668.28 (261.65)

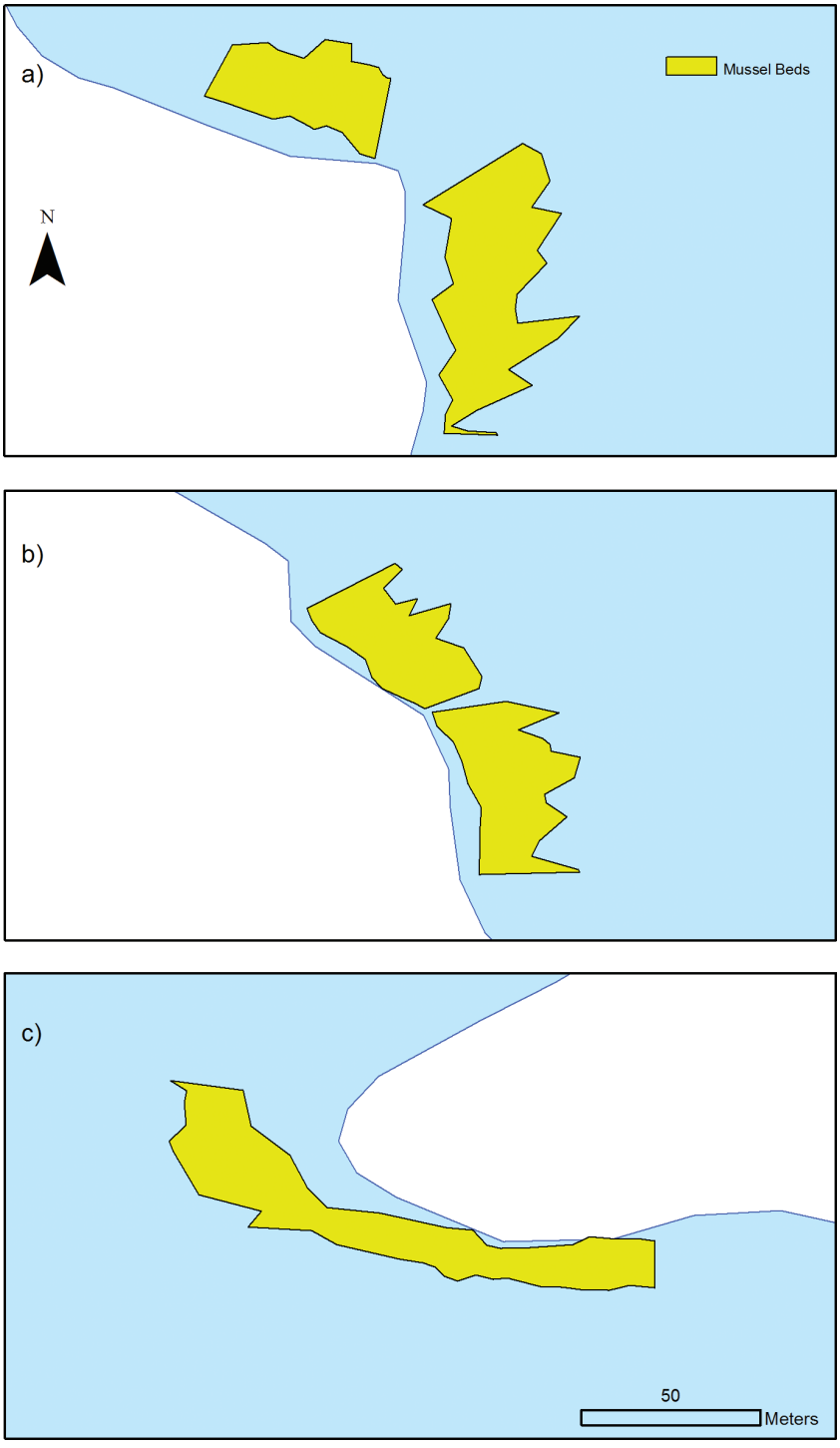

Figure 2. Delineated Rocky Mountain ridged mussel beds at index sites: a) Dog Beach 1 (southern bed) and 2 (northern bed) b) Kinsmen Beach 1 (southern bed) and 2 (northern bed) c) 3 Mile.

Occurrence of Eurasian watermilfoil

Eurasian watermilfoil could be seen within the boundaries of the mussel beds at all three reference sites and four of the five index sites (Table 3). Individual plants occurred sporadically at three index sites (Dog Beach 1, Kinsmen Beach 1 and 2). Two Eurasian watermilfoil beds were seen near or within part of the mussel beds at 3 Mile and Kinsmen Beach 1. Both plant beds were extensive in that the substrate was covered by mats of plants. At 3 Mile, the plants were not seen on the mussel bed, but remained 2–5 m away in deep water. The plant bed was located where water depth increased beyond the depth where mussels are typically found. At Kinsmen Beach 1, the Eurasian watermilfoil had encroached on to the southern end of the mussel bed (first 9 m of the baseline) and the substrate had become muddy (Figure 3). This represented only the

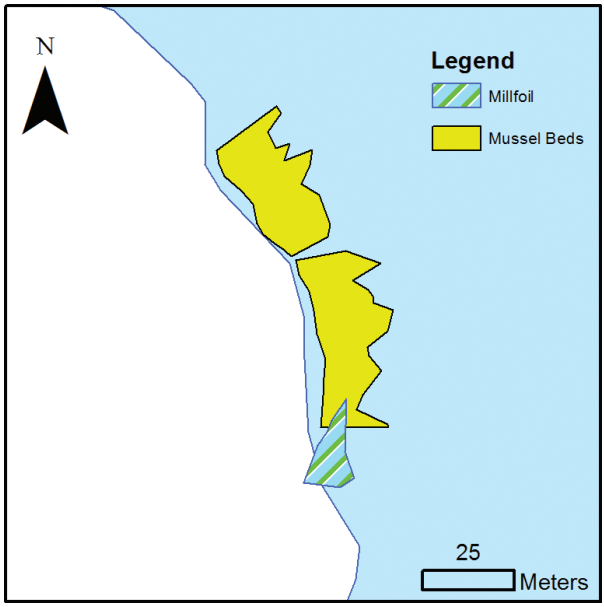

Figure 3. Location of Rocky Mountain ridged mussel (*Gonidea angulata*) beds surveyed at Kinsmen Beach 1 (southern bed) and 2 (northern bed) index sites with encroaching Eurasian watermilfoil (hatched green/blue) in Okanagan Lake, British Columbia in August 2019.

Table 3. Qualitative description of the co-occurrence of Eurasian watermilfoil (*Myriophyllum spicatum*) in Rocky Mountain ridged mussel (*Gonidea angulata*) index sites in Okanagan Lake, British Columbia in August 2019.

Index site	Description
Dog Beach 1	Individual plants found sporadically in the bed.
Dog Beach 2	No plants present.
Kinsmen Beach 1	Individual plants found throughout the mussel bed. Extensive dense plant bed overlapping a portion of the mussel bed.
Kinsmen Beach 2	Individual plants found sporadically in the mussel bed.
3 Mile	Extensive, dense plant bed within 2 m of the mussel bed

leading edge of an extensive Eurasian watermilfoil bed. The Dog Beach 2 index site is a segregated dog swimming area where the substrate is regularly disturbed. No plants were seen at this index site.

Discussion

The proposed management regime in Okanagan Lake would dictate a 100-metre buffer zone between the Rocky Mountain ridged mussel beds and Eurasian watermilfoil control activities (Lirette 2019). The size of this buffer zone created concerns that restrictions on the spatial extent of Eurasian watermilfoil control due to the presence of Rocky Mountain ridged mussels would impede control of the invasive plant, threatening economic and recreational use and safety on the Lake (Duncan 2019). This conflict was highlighted to the federal Minister of Fisheries and Oceans when considering the change in the conservation status of the species. Our results show that the perceived conflict between Rocky Mountain ridged mussel management and Eurasian watermilfoil control did not occur at all index sites and that standard methods of Eurasian watermilfoil control could be conducted within distances of less than 100 m from a mussel bed. Separation of mussel beds and the Eurasian watermilfoil, either due to a small number of plants or plants existing deeper than the preferred mussel habitat, suggests that Eurasian watermilfoil control activities could be conducted near some mussel beds and that early intervention may prevent more extensive overlap of these two species.

Rototilling can remove the root of the plant in water up to 4.5 m deep, whereas cutting can remove it in water as shallow as 2 m. The surveyed mussel beds were in water as shallow as 38.1 cm and as deep as 175.3 cm. The less invasive cutting method would be suitable throughout the depth of these beds.

Our findings demonstrate that the five index sites varied in mussel bed density (0.13–1.23 mussels/m^2) and corresponding population estimates (128.88 to 1,668.28), as did the extent of incursion of milfoil into the beds. These findings support recommendations for site-specific management actions, as opposed to generic, Lake-wide recommendations to balance the need for invasive species control and endangered species management.

For example, removal of the invasive plant at 3 Mile could occur using rototilling without disturbing the existing mussel bed. If plants are not removed from the Kinsmen Beach 1 index site, they will likely continue to take over the mussel bed. We subjectively noted an increase in the extent of mud and siltation at this site compared to surveys in previous years. Cutting of plants overlapping the mussel bed would be recommended for this area. The rest of the plant bed, further away from the mussel bed, could be removed by rototilling without impacting the mussel bed. This recommendation is for this site only and should not be applied to other locations without investigation.

Managing one ecosystem risk, such as an invasive species, can have unintended negative impacts on other goals, such as endemic species conservation. Ecosystem managers have three options when faced with conflicting invasive species and conservation goals; (1) manage the impacts of the invader and accept the collateral damage;

(2) abandon management of the invader and accept its impacts or (3) seek a compromise strategy that allows both goals to be attained (Buckley and Han 2014). The value of Okanagan Lake to local tourism, recreation and real estate preclude option 2. Societal expectations and legislative obligations to protect rare and endangered species preclude option 1. A compromise approach is needed.

There is community, regulatory and scientific information to support the belief that the presence of Eurasian watermilfoil in Okanagan Lake is deleterious to the health of the Rocky Mountain ridged mussel, as well as to the economic and recreational use of the Lake by people. Lampert et al. (2014) concluded that, in general, optimal management of multiple invasive species and conservation goals simultaneously require less-intensive investment over extended periods to fit with the timescale of natural processes. The tremendous data gaps complicate selection of management actions that meet this species evolved needs, especially in the face of concurrent threats from invasive species, climate change and foreshore habitat damage. Conservation success is increasingly seen not just as removal of the threat of extinction, but rather the development of self-sustaining, healthy, resilient species (Stephen and Wade 2018).

Conclusion

We suggest that Eurasian watermilfoil control is one strategy to protect critical resources needed for Rocky Mountain ridged mussel resilience and, therefore, Eurasian watermilfoil control is a shared conservation and invasive species goal. Expanding this work to other areas can further delineate the nature of the overlaps of mussels and Eurasian watermilfoil. Such site-specific information may allow for an integrated strategy to address conservation goals without compromising invasive species management goals by setting evidence-based buffer zones and/or tailoring Eurasian watermilfoil control activities to the nature of site-specific mussel-watermilfoil overlaps.

Acknowledgements

This work was partially funded by the Species at Risk Program of Fisheries and Oceans Canada, Science, Pacific Region.

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