COSEWIC
Assessment and Status Report

on the

Rocky Mountain Ridged Mussel
Gonidea angulata

in Canada

ENDANGERED
2010

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

COSEWIC status reports are working documents used in assigning the status of wildlife species suspected of being at risk. This report may be cited as follows:

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Previous report(s):

COSEWIC. 2003. COSEWIC assessment and status report on the Rocky Mountain Ridged Mussel *Gonidea angulata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 29 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

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For additional copies contact:

COSEWIC Secretariat
c/o Canadian Wildlife Service
Environment Canada
Ottawa, ON
K1A 0H3

Tel.: 819-953-3215
Fax: 819-994-3684
E-mail: COSEWIC/COSEPAC@ec.gc.ca
http://www.cosewic.gc.ca

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COSEWIC
Assessment Summary

Assessment Summary – November 2010

Common name
Rocky Mountain Ridged Mussel

Scientific name
Gonidea angulata

Status
Endangered

Reason for designation
This mussel, one of only a few species of freshwater mussel in British Columbia, is restricted in Canada to the Okanagan basin. Historically, channelization and water regulation in the Okanagan River have affected mussel beds and caused population reduction. Additional sites have been found since the original COSEWIC assessment (2003). Currently, Zebra and Quagga (dreissenid) Mussels are the most serious potential threat to the native mussel. Dreissenid mussels have had devastating effects on native unionid communities elsewhere, such as in the Great Lakes region. A recent assessment of the sensitivity of the Okanagan basin to dreissenid mussels demonstrated that the latter could spread quickly and establish intense infestation on native mussels once introduced. Within the foreseeable future, the introduction of dreissenids into the Okanagan basin is likely because they can survive for days out of water and are known to be transported between water bodies on trailered watercrafts; dreissenid mussels have been intercepted on trailered boats heading to British Columbia in recent years. Ongoing foreshore and riparian development, and some methods of control of invasive Eurasian Watermilfoil, reduces habitat and affects water quality.

Occurrence
British Columbia

Status history
Designated Special Concern in November 2003. Status re-examined and designated Endangered in November 2010.

COSEWIC
Executive Summary

Rocky Mountain Ridged Mussel
Gonidea angulata

Species information

Rocky Mountain Ridged Mussel (*Gonidea angulata*) is a freshwater bivalve mollusc with a thick-walled shell up to 125 mm long, trapezoidal in shape, and with a prominent posterior ridge that runs from the dorsal margin to the posterior edge. The outside of the shell is yellow-brown to black-brown, while the inner shell surface is centrally white or salmon, but pale blue posteriorly and near the edges. The two shells are connected by a ligament, but the interlocking projections, or hinge teeth, are weakly developed in this species. The parasitic larvae, called glochidia, are about 1.5 mm long and are hookless (without ventral shell hooks).

Distribution

Rocky Mountain Ridged Mussel is a western North American species. It is distributed from southern British Columbia to southern California, and eastward through northern Nevada and Idaho. Less than 5% of the global range occurs in Canada in southern British Columbia within the Okanagan basin, specifically, Okanagan Lake, Okanagan River, Skaha Lake, Park Rill, Vaseux Lake, and Osoyoos Lake.

Habitat

Rocky Mountain Ridged Mussel has been found within several lakes, one creek, and one river in the Okanagan basin. The majority of individuals have been observed in mud to mud-sand substrate, but they have also been found wedged within cobbles. This species has been found at depths ranging from 1–3 m, but surveys at greater depths have not been conducted.

Biology

The life cycle of Rocky Mountain Ridged Mussel follows the general reproductive biology of freshwater mussels, which includes obligate parasitism of a host fish. Sexual maturity is likely reached within three years and the average age of a breeding adult is estimated to be 15 years. Reproductive timing has not been described for this species in Canada; however, expelled conglutinates (packages of glochidia) from several females were observed on one occasion during the month of June. Dispersal is limited to host-fish movement. In the United States, Hardhead, Tule Perch, and Pit Sculpin are confirmed host fishes, but the host species in Canada are unknown.

Population sizes and trends

Population sizes and trends cannot be assessed as only 14 records exist from 1906–2002. Recent surveys (2004–08) confirmed historical records or discovered sites in the Okanagan River, Skaha Lake, Vaseux Lake and Okanagan Lake.

Limiting factors and threats

Loss and degradation of habitat has likely been the historically most significant threat to the Rocky Mountain Ridged Mussel in Canada. Perhaps the greatest potential threat to the Rocky Mountain Ridged Mussel in Canada is, however, the introduction of the invasive Zebra and Quagga Mussels into the Okanagan basin. Both of these mussels have become established in eastern North America since the late 1980s, and are spreading westward in the U.S. At least 12 reports of boats being trailered on land from known infested waters in Montana and Idaho to southern B.C. have been documented in the past 10 years. Once established, these mussels frequently develop into dense formations that may quickly infest lakes or rivers and have had devastating impacts on native unionid communities, such as has been experienced in the Great Lakes region.

Channelization and the creation of dams and weirs cause direct, physical disturbance and create barriers to potential host fish movement. Rapid human population growth throughout the Okanagan basin has resulted in alteration of shoreline and littoral zones and has added pollutants into the watershed, and introduced non-native species into the basin, including (besides Zebra and Quagga Mussels) fish, Eurasian Watermilfoil and crustaceans.

Special significance of the species

This is the only living species in its genus, *Gonidea*. The genus is not closely related to any other North American mussel. The ecological role of Rocky Mountain Ridged Mussel in Canada has not been studied; however, freshwater molluscs are important contributors to freshwater ecosystems and can be used as indicators of freshwater ecosystem health.

Existing protection

Rocky Mountain Ridged Mussel is protected under the jurisdiction of the federal government (Fisheries and Oceans Canada). Under the federal *Fisheries Act*, freshwater mussels are included under the definition of “fish” and receive the same protection as fish. This species is currently a species of Special Concern (Schedule 1) under the Canadian *Species at Risk Act .* It is ranked G3 globally and S1 in the province of British Columbia.

TECHNICAL SUMMARY

Gonidea angulata
Rocky Mountain Ridged Mussel — Gonidée des Rocheuses
Range of occurrence in Canada (province/territory/ocean): British Columbia

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines(2008) is being used) 1–3 years to reach sexual maturity; maximum age reported is 24 yrs; proposed lifespan 20–30 years (COSEWIC 2003)	~ 15 yrs possibly
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown, but given numbers of empty shells at some sites, likely declining
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline clearly reversible and understood and ceased?	No
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence Previous EO was 210 km^2 (COSEWIC 2003) apparent increase in EO is likely due to increased search effort; see **Canadian range**	1585 km^2
Index of area of occupancy (IAO) (Always report 2x2 grid value).	80 km^2
Is the total population severely fragmented?	Unknown
Number of locations*	1
Is there an [observed, inferred, or projected] continuing decline in extent of occurrence?	Unknown decline at present; projected continuing decline if threat is manifested
Is there an [observed, inferred, or projected] continuing decline in index of area of occupancy?	Unknown decline at present; projected continuing decline if threat is manifested
Is there an [observed, inferred, or projected] continuing decline in number of populations?	No but potentially declining
Is there an [observed, inferred, or projected] continuing decline in number of locations*? Based on verified mussel presence in Canada.	Likely stable

* See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term.

Is there an [observed, inferred, or projected] continuing decline in [area, extent and/or quality] of habitat? Declines assumed for area and quality.	Observed and projected decline in area, extent and quality of habitat
Are there extreme fluctuations in number of populations?	No
Are there extreme fluctuations in number of locations*?	No
Are there extreme fluctuations in extent of occurrence?	Unknown, but unlikely
Are there extreme fluctuations in index of area of occupancy?	Unlikely

Number of Mature Individuals (in each population)

Population	N Mature Individuals
Okanagan River drainage	Minimum ~ 1,400 but total number unknown
Total	Unknown

Quantitative Analysis

Probability of extinction in the wild is at least [20% within 20 years or 5 generations, or 10% within 100 years].	Not available

Threats (actual or imminent, to populations or habitats)

Most serious, plausible threat:

- introduction and establishment of Zebra Mussel and/or Quagga Mussel in the Okanagan River basin.

Current significant threats:

- ongoing foreshore/riparian development affecting quality/quantity of habitat especially on lake shorelines,
- regular rototilling of invasive Eurasian Watermilfoil beds.

Historical threat:

- channelization and water regulation in Okanagan River.

Rescue Effect (immigration from outside Canada)

Status of outside population(s)? U.S.: N3, considered declining	
Is immigration known or possible? Okanagan basin – unlikely (from Okanogan River) This assessment only considers rescue for known, confirmed rivers and lakes. Immigration from the Similkameen River is possible (i.e., no obvious barriers to movement) but no evidence exists of Canadian presence (historically or current) in this river.	Possible, but limited at best
Would immigrants be adapted to survive in Canada?	Unknown from the Okanogan River into Osoyoos Lake
Is there sufficient habitat for immigrants in Canada? Unknown if riverine immigrants (from the Okanogan River) could move into a lake environment (Osoyoos Lake). It is unknown if barriers in the Okanagan River would be an impediment to host fishes and mussels migrating north from Osoyoos Lake.	Lake habitat: Yes Riverine habitat: not likely
Is rescue from outside populations likely?	No

∗ See Definitions and Abbreviations on COSEWIC website and IUCN 2010 for more information on this term.

Current Status

COSEWIC: Designated Special Concern in November 2003. Status re-examined and designated Endangered in November 2010.

Additional Sources of Information: None

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code:** B1ab(i,ii,iii,v)+2ab(i,ii,iii,v)
Reasons for designation: This mussel, one of only a few species of freshwater mussel in British Columbia, is restricted in Canada to the Okanagan basin. Historically, channelization and water regulation in the Okanagan River have affected mussel beds and caused population reduction. Additional sites have been found since the original COSEWIC assessment (2003). Currently, Zebra and Quagga (dreissenid) Mussels are the most serious potential threat to the native mussel. Dreissenid mussels have had devastating effects on native unionid communities elsewhere, such as in the Great Lakes region. A recent assessment of the sensitivity of the Okanagan basin to dreissenid mussels demonstrated that the latter could spread quickly and establish intense infestation on native mussels once introduced. Within the foreseeable future, the introduction of dreissenids into the Okanagan basin is likely because they can survive for days out of water and are known to be transported between water bodies on trailered watercrafts; dreissenid mussels have been intercepted on trailered boats heading to British Columbia in recent years. Ongoing foreshore and riparian development, and some methods of control of invasive Eurasian Watermilfoil, reduces habitat and affects water quality.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable – number of mature individuals and trend unknown.
Criterion B (Small Distribution Range and Decline or Fluctuation): B1: EO (1,585 km²) <5,000 km²; B2: IAO (80 km²) <500 km²; a: known to exist at 1 location; b: inferred continuing decline in (iii) area, extent and/or quality of habitat (ongoing development), projected continuing decline in (i) IAO, (ii) EO, (v) number of mature individuals (dreissenid mussel infestation). Does not meet c: no extreme fluctuations known in EO, IAO, number of locations/populations, or number of individuals.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable – though minimum of ~1,400 observed, total number of mature individuals unknown; trend unknown.
Criterion D (Very Small or Restricted Total Population): Meets Threatened, D2: Number of locations (1) is <5 and species is prone to the effects of human activities (introduction of dreissenid mussels) within a very short time period. D1 not applicable – number of individuals > 1000.
Criterion E (Quantitative Analysis): Not available.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2010)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment Canada / Environnement Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

The Canadian Wildlife Service, Environment Canada, provides full administrative and financial support to the COSEWIC Secretariat.

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2010

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SPECIES INFORMATION

Name and classification

Scientific name: *Gonidea angulata* (Lea, 1838)
English common names: Rocky Mountain Ridged Mussel (Clarke 1981; COSEWIC 2003); Western Ridged Mussel (Turgeon *et al.* 1998)

French common name: gonidée des Rocheuses (Martel *et al.* 2007)

The current authority for the nomenclature of freshwater molluscs in Canada and the United States is Turgeon *et al*. (1998):

Phylum Mollusca
Class Bivalvia
Order Unionoida
Family Unionidae
Genus *Gonidea*
Species *Gonidea angulata*

Gonidea angulata is recognized as a valid species by Turgeon *et al.* (1998), Clarke (1981), and others. It is the only species in the genus, and a thorough study by Lydeard *et al.* (1996) concluded that *Gonidea* is not closely related to any other extant North American unionoid. Genetic studies by Rosenberg *et al.* (1994) and Graf (2002) place *Gonidea* in the subfamily Ambleminae which is endemic to North and Central America (Graf and Cummings 2007).

The relationship of *G. angulata* with other unionid mussels has been problematic. Early systematic work by Ortmann (1910, 1916) regarded *Gonidea* as exceptionally distinctive, belonging to its own subfamily or family and ranking among North American Unionidae closest to the Ambleminae or Amblemidae (e.g., Heard and Guckert 1971; Davis *et al.* 1978; Davis and Fuller 1981). Other authors (e.g., Heard 1974; Taylor 1985, 1988) thought *Gonidea* share similarities with Asian taxa. Based primarily on anatomical characters, Nagel *et al.* (1998) suggested a close relationship between a problematic European taxon, *Potamida littoralis,* and the tribe Gonideini. Current research indicates that *Gonidea angulata* is the only extant member of the genus, but four fossil taxa have also been documented (Watters 2001).

Morphological description

Clarke (1981) provided the following morphological description of *G. angulata*: “Shell up to 125 mm long, 65 mm high, 40 mm wide, and with shell wall up to about 5 mm thick at mid-anterior; variable in form but typically rather thin, trapezoidal in shape, with posterior margin obliquely flattened and relatively broad, and with a sharp and prominent posterior ridge running from the umbo [raised, rounded area along the dorsal margin, also called the “beak”] to the angular basal posterior margin of each valve**.** Shell with obscure radial sculpturing on the posterior slope and readily apparent growth rests.

Periostracum yellowish brown to blackish brown, without rays, smooth on the disc, and roughened on the posterior slope. Nacre centrally white or salmon, but pale blue posteriorly and near the margin. Beak sculpture composed of about eight rather coarse, concentric ridges that are straight in the centre and curved at both ends. Hinge teeth irregular and poorly developed; pseudocardinal teeth compressed, low, laterally expanded, 1 in the right valve and none or 1 in the left; lateral teeth absent" (Figure 1).

Figure 1. Live *Gonidea angulata* at Vaseux Lake, July 2006. Photo by L. Gelling.

Gonidea angulata is readily distinguished from all other freshwater mussel species found in its Canadian range (floaters, *Anodonta* spp. and Western Pearlshell, *Margaritifera falcata*) by the distinct, prominent ridge that runs from the umbo to the posterior margin of the shell. Interlocking pseudocardinal teeth on the hinge, below and slightly in front of the umbo are also distinguishing features. *Anodonta* spp. lack hinge teeth, while the teeth of *M. falcata* are more prominent, but much weaker than many other species of mussels.

There is no morphological description for *G. angulata* conglutinates (mucilaginous packages containing glochidia [larvae]) in the literature, but conglutinates have been observed on one occasion in Canada (see **Life cycle and reproduction**; Figure 2). Individual conglutinates were approximately 1 cm long, oblong in shape and were creamy-white (Figure 2). Glochidia are small (average: 0.153 ± 0.007 mm in length) and hookless (Figure 3), which distinguishes them from *Anodonta* spp. glochidia, which are larger (0.2–0.4 mm) and have ventral shell hooks (Haley *et al*. 2007).

Figure 2. *Gonidea angulata* conglutinates. Okanagan Lake (Dog Beach, Summerland), June 2007.

Figure 3. *Gonidea angulata* glochidium extracted from the marsupium of a gravid female collected from the Pit River, California, June 2005. Photo by L. Haley (Haley *et al.* 2007).

Genetic description

The genetic population structure of *G. angulata* has not been studied for populations in Canada and is currently being evaluated for populations in the United States. Preliminary results based on mitochondrial DNA sequencing for populations in the United States indicate that there is no evidence of deep divergence (i.e., pre-glacial separation; Mock pers. comm. 2009). With respect to current population structure, it is impossible to draw any conclusions as to the degree to which separation has or may occur within the Okanagan basin without detailed genetic research. No obvious physical barriers for either larvae or host fishes are apparent within Okanagan Lake that might influence gene flow. Anthropogenic barriers (see **Habitat trends**) between the lake and downstream components, however, may have reduced the extent to which both larvae and host fish are able to disperse, potentially affecting gene flow, and it is possible that barriers do exist between Canadian and U.S. populations which could render Canadian populations genetically distinct from those in the U.S. if no gene flow is occurring (due to large dams, etc.) or if there was a pre-glacial separation between Canada and the U.S.

Should presence in additional river basins be confirmed (see **Canadian range**), these populations would be considered reproductively isolated from the Okanagan basin, and likely genetically distinct.

Designatable units

In Canada, *G. angulata* is within the Pacific COSEWIC National Freshwater Biogeographic Zone (COSEWIC 2009). Because the species is confined to one ecological unit, there are no recognized subspecies, and the genetic structure is unknown for the Canadian population, there is one designatable unit.

DISTRIBUTION

Global range

Gonidea angulata is found in western North America, ranging from southern British Columbia to southern California, eastward through northern Nevada and Idaho (Figure 4). Areas where the species is known or thought to be extirpated in the United States are identified below.

Figure 4. Likely historical range of *Gonidea angulata* in British Columbia and the western United States (COSEWIC 2003).

United States range

Gonidea angulata had been reported from numerous coastal and interior rivers in Washington, Oregon, Idaho, northern Nevada, and California. In particular, *G. angulata* is found in three transboundary rivers shared with British Columbia: the Similkameen and Okanogan (spelled “Okanagan” in Canada) rivers in Washington and the Columbia River mainstem in Oregon. Historic occurrences were also reported in the upper Columbia River watershed in western Montana, specifically in Clark Fork River or Kootenai River (spelled “Kootenay” in Canada) (Henderson 1924; Nedeau *et al.* 2005) and in Utah (COSEWIC 2003, but as of October 2008, there have been no new reports for Montana or Utah [Oliver pers. comm. 2008; Stagliano pers. comm. 2008]).

While still present and even numerous in some areas, *G. angulata* is now thought extirpated in many places. In particular, the species was once considered to occur in numerous rivers throughout California but is now considered extirpated through most of the Central Valley and southern areas, although it was still present in 1981 in other river systems in the state (Taylor 1981). Similarly, it is known to be extirpated from much of its original range in the Snake River, a large tributary of the upper Columbia River located in Idaho (Frest and Johannes 1995).

Canadian range

In Canada, *G. angulata* is at the most northern periphery of its global range, and less than 5% of the global distribution is within the Okanagan basin in southern British Columbia. Records for this species in Canada have only been verified for collection sites in the Okanagan River basin. Specifically, this species has been found within valley-bottom water bodies including, from north to south, Okanagan Lake, Skaha Lake, Okanagan River, Vaseux Lake, Park Rill and Osoyoos Lake. There are 12 historical (1906–2002) records from eight sites within the Okanagan basin (Table 1); recent inventory (2005–08) targeting *G. angulata* in the area has resulted in an additional 51 individuals from 25 survey sites (Figure 5). Although these sites are all connected as part of the same river system, it is possible that the population is fragmented and/or disjunct, due to the presence of multiple dams and weirs that may prevent host fish movement throughout the basin (see **Habitat trends**). Weirs or, as they are sometimes known, “vertical drop structures”, are sills that are built to ease the steepness, and thus slow the water as it flows along a channelized river. The structures were designed so fish could pass through them, but they limit the movement of some species, including Kokanee (*Oncorhynchus nerka*) (Rae 2005).

Table 1. Historical records of *Gonidea angulata* (1906–2002).

Collection Date	Site	Specimens collected live or dead (empty shells)	Collector	Notes	Museum	Museum Collection No.	Source
1906-03	Penticton; Okanagan River where it leaves Okanagan Lake	unknown (2 empty shells but fairly fresh)	G.E. Winkler		Canadian Museum of Nature	CMNML 093118	Canadian Biodiversity Information Facility 2005; Gagnon. pers. comm. 2005
1991-08-09	Skaha Lake, Penticton.	unknown; (the 2 specimens are shells)	D.W. Taylor	Museum specimen has green algae on inside of shell indicating that it was likely collected dead (Sendall pers. comm. 2008)	Royal British Columbia Museum	RBCM 993-00004-003	Sendall pers. comm. 2008
1960-08-19	Okanagan Falls	empty old shells	R.J. Drake	collected from "Campsite #12"	Canadian Museum of Nature	CMNML 016017	Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005
1960-08-20	Okanagan Falls	empty old shells	R.J. Drake		Canadian Museum of Nature	CMNML 009683	Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005
1963-06-12	Okanagan River, Okanagan Falls, British Columbia	unknown if collected live or dead	D.W. Taylor		Smithsonian National Museum of Natural History	NMNH 652845	NMNH 2009
1972-08-06	Vaseux Lake; north of Oliver at Public Beach	4 live	A.H. Clarke, B.T. Kidd		Canadian Museum of Nature	CMNML 067553	Clarke 1981; Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005
2002-08-02	Park Rill, within the city limits of Oliver.	½ a shell	Osoyoos Lake Water Quality Society				COSEWIC 2003
1983-10-04	Half way between Oliver and Osoyoos Lake entrance	3 live	T. Tuominen, S. Yee		Canadian Museum of Nature	CMNML 086690	Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005
1982-10-27	Half way between Oliver and Osoyoos Lake entrance	1 live	T. Tuominen, S. Yee		Canadian Museum of Nature	CMNML 086691	Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005
1982-10-28	Okanagan River; upstream from entrance to Osoyoos Lake	1 live	T. Tuominen, S. Yee		Canadian Museum of Nature	CMNML 086692	Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005

Collection Date	Site	Specimens collected live or dead (empty shells)	Collector	Notes	Museum	Museum Collection No.	Source
1983-10-04	Okanagan River; upstream from entrance to Osoyoos Lake	3 live	T. Tuominen, S. Yee		Canadian Museum of Nature	CMNML 086693	Canadian Biodiversity Information Facility 2005; Gagnon pers. comm. 2005
1990-08-16	Osoyoos Lake, N. side of Haynes Point Provincial Park	2 shells (?)	D.W. Taylor	Museum specimen has green algae on inside of shell indicating that it was likely collected dead (Sendall pers. comm. 2008)	Royal British Columbia Museum	RBCM 993-00003-002	Sendall pers. comm. 2008
Unknown	Kootenay River	unknown	unknown				Clarke 1981
1890s	Vancouver Island	unknown	From the Rush collection		University of Michigan Museum of Zoology	107902	Appleton pers. comm. 2008

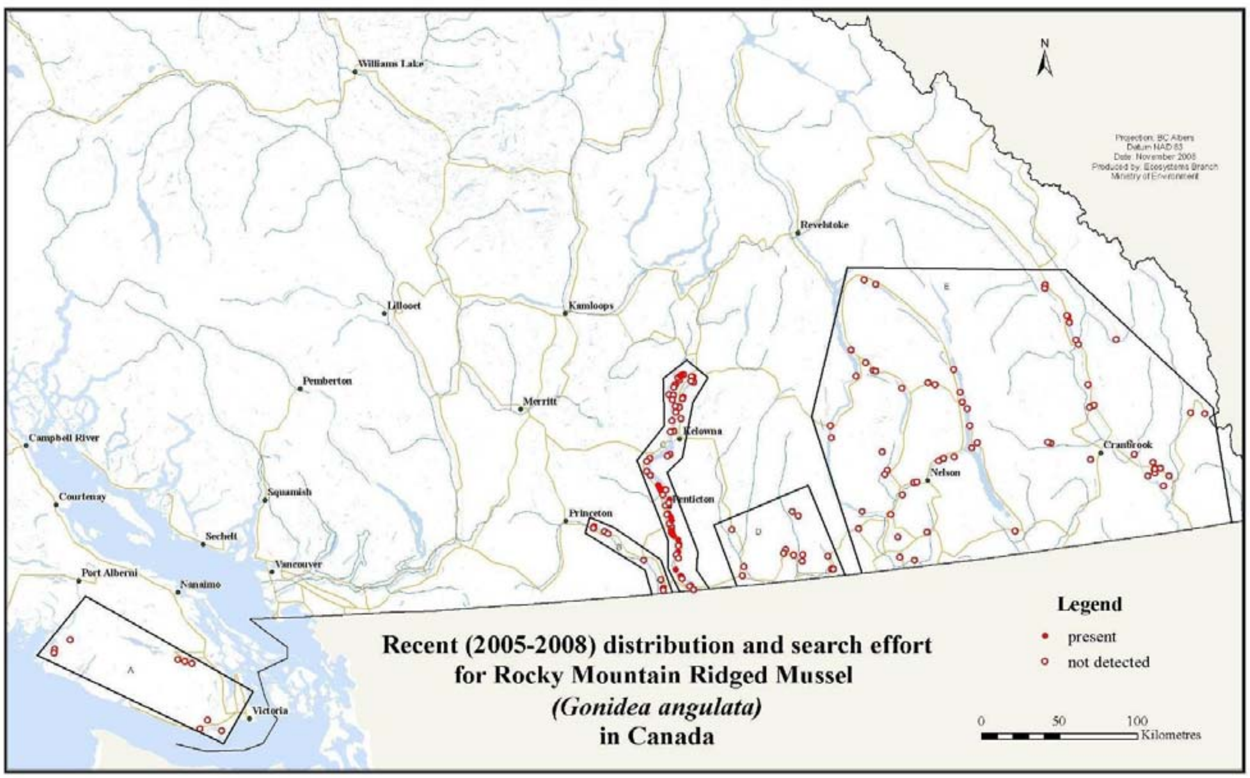

Figure 5. Recent (2005–08) search effort and distribution of *Gonidea angulata* in Canada. From west to east the areas are: Vancouver Island, Similkameen basin, Okanagan basin, Kootenay Boundary, and Central and East Kootenays. Map prepared by B. Woods, B.C. Ministry of Environment.

Lindsay (2000) reported *G. angulata* at an archaeological site (DiRa-9) within the Thompson River drainage, much farther north than any other references and outside of the Columbia River drainage; however, the site was later corrected to refer to an archaeological site near the Similkameen River which drains into the Okanagan River only after it enters Washington State. Upon further research, it was found that *G. angulata* was not confirmed at this site, and that the reference lists all species that could potentially occur in southern B.C., not just species that were found in the midden (Suttill pers. comm. 2008). To conclude, *G. angulata* has only been reported in the portions of the Similkameen River south of the international border where the farthest upstream report of *G. angulata* has been reported is immediately below the outlet of Palmer Lake, approximately 15 km downstream of the border (Kreuger *et al.* 2007). Recent surveys (2006, 2007 and 2009) in the lowermost section of the Canadian portion of the Similkameen River reported *Margaritifera falcata* but no *G. angulata* (Pollard unpublished data). On further consideration of satellite imagery for this entire section of the Similkameen, a distinct break in river channel morphology was noted immediately south of the border as the river changed from an unconstrained channel with side channels and numerous depositional gravel and sand bars to a more constrained channel with more stable riparian areas not prone to movement during high flow periods (Pollard pers. obs.). Although its presence cannot be ruled out, this break may explain the absence of *G. angulata* in the Canadian portion of the Similkameen River.

There are two other records of *G. angulata* in B.C. outside of the Okanagan basin; both are considered unverified. There is a single, undated record from “Kootenay River” (Clarke 1981); however, the specimen has not been located, and despite recent, considerable search effort throughout the Kootenay Boundary and Central and East Kootenay regions, this species has not been found (Table 2). There is also one specimen located at the University of Michigan Museum of Zoology labelled “Vancouver Island”, dating from approximately 1890 (Appleton pers. comm. 2008), but there have been no other reports from the island, historically or with recent search effort (Table 2). In conclusion, this report only considers the verified records from the Okanagan basin.

Table 2. Recent search effort targeting *Gonidea angulata* (2005–08).

Search area (see Figure 10 for map of sites)	Number of sites	Person-hours (minimum number of hours)	Shore-line (linear) distance searched (minimum number of kilometres)	*G. angulata* found?
Vancouver Island	8	13.6	5.3	no
Similkameen basin	7	13.2	4.0	no
Okanagan basin	86	147.4	31.5	yes
Kootenay Boundary	15	9.3	2.1	no
Central and East Kootenays	63	62.6	47.9	no
Total	**179**	**429.7**	**90.8**	

In the previous report, the extent of occurrence (EO) was reported as 210 km^2 (COSEWIC 2003), but details of its calculation were not provided. The current EO is 1,585 km^2 and was calculated in ArcMap™ 9.2 using the XTools Pro™ Convex Hull extension and captured historical and recent records including land. This larger EO calculation reflects increased search effort from 2005–09; it is not the result of an expanding population since the previous status assessment.

The estimated index of area of occupancy (IAO) is 80 km^2. The IAO was calculated using a 2 × 2 km grid that was overlaid on the points representing current survey sites that contained shells or live specimens. The IAO calculation was based on IUCN (2008) and COSEWIC methods (2009). The area of occupancy was not formally calculated but was previously documented as "less than EO" (210 km^2; COSEWIC 2003).

Although continuing declines in EO and IAO are unknown at present, continuing decline is expected for both of these if the threat of dreissenid mussels (Zebra Mussels, *Dreissena polymorpha*, and Quagga Mussels, *D. rostiformis bugensis*) is manifested (see **LIMITING FACTORS AND THREATS**).

Given the lack of information available on population structure or host species, it is impossible to estimate how many breeding units or populations may occur in this basin, and to what degree gene flow occurs throughout. While existing information on distribution and abundance does not suggest severe habitat fragmentation, the habitat has undoubtedly been fragmented to some degree by anthropogenic activities including shoreline alteration, dams, and river channelization. To what degree these changes affect host or mussel dispersal is unknown.

Number of locations

If the threat of invasive dreissenid mussels is considered the most serious, plausible threat within the next 10 years (see **LIMITING FACTORS AND THREATS**), then the number of locations could be one. A successful introduction of dreissenid mussels into the Okanagan basin could rapidly spread through essentially the whole lake system and likely affect all individuals of *G. angulata*. If there were barriers and limitations to a dreissenid invasion (for example, areas where dreissenids do not reach or are less successful at colonizing due to physiographic barriers or unsuitability of habitat (nearshore refuge areas) — such is the case for some at-risk unionids in Ontario [see, for example, COSEWIC 2010]) — the number of locations might be more than one. However, given the interconnectedness of the basin's lakes, the high recreational boating use in the region, and that all recent sites where *Gonidea angulata* has been found alive are in the lakes (as opposed to upstream tributaries that might be afforded some protection from dreissenid mussel settlement), more than one location seems unlikely.

HABITAT

Habitat requirements

Freshwater mussels can live in a well-defined habitat at one site, but will often occur in very different habitats at other sites (Coker *et al*. 1921; Strayer 1981, as cited in Strayer 2008); this appears to be the case for *G. angulata* throughout its range and in Canada. In the United States, this species is found in creeks and rivers of all sizes, is rarely found in lakes or reservoirs and is *usually* absent from very soft substrates (Frest and Johannes 1995; Nedeau *et al.* 2005). Conversely, in Canada, it has been observed predominantly in lakes where soft substrate is present. There are few details on substrate type within the Canadian historical records. At Vaseux Lake, mussels were in muddy sand along the shoreward margin of a bed of pondweed (*Potamogeton* sp.) (Clarke 1981), and very young specimens were noted from coarse plant detritus at the mouth of the Okanagan River in 1991 (COSEWIC 2003). The 2003 COSEWIC report specifies that this species requires cold, clear, oligotrophic (nutrient-low) waters and prefers constant flow, shallow depths (typically < 3 m in depth) and well-oxygenated substrate.

At recent lake survey sites (2005–08), *G. angulata* was primarily observed in substrate consisting of mud and/or a combination of mud and sand (Gelling, unpublished data) or wedged between cobbles in soft substrates (Lauzier pers. comm. 2008). Some groups or individuals were found in substrate lacking aquatic vegetation, and at other sites, low-lying vegetation was interspersed among individual mussels (Gelling, unpublished data). The few live mussels noted in the unchannelized, natural section of the Okanagan River below McIntyre Dam were in sandy depositional areas behind large boulders or wedged in cobble substrate (Pollard unpublished data).

Recent surveys in the Okanagan basin reported the largest groups of live *G. angulata* in Okanagan Lake, a large, oligotrophic lake with significant wave action along exposed shorelines that may mimic the constant flow found in the more typical river habitats to the south (Pollard pers. obs.). In contrast, one of the lakes where only shells are reported from recent collections in 1990 and 2005 (Osoyoos Lake) is considered eutrophic and shallow with the bottom frequently experiencing oxygen depletion in the warm summer months.

Strayer (2008) concluded that traditional abiotic factors frequently used to describe aquatic habitats are often ineffective at predicting mussel presence in general and may explain why a wide array of habitat types are reported for *G. angulata* across its range. Instead, he recommended that habitat requirements be considered from the perspective of what a freshwater mussel needs to complete its life cycle successfully.

Gonidea angulata seems to prefer areas with stable habitat conditions and appears to avoid areas with shifting substrates, periodic dewatering or extreme water level fluctuations, or with seasonal hypoxia or anoxia (COSEWIC 2003); this is consistent with basic requirements of stable, supporting substrates that remain wet

(Strayer 2008). At some U.S. sites, turbidity changes markedly over a normal water year, but the species seems to be absent from streams with continuously turbid water, such as glacial melt water streams (e.g., Hood River, Oregon) while being present in nearby streams that are only seasonally turbid, such as the Deschutes and John Day rivers of Oregon (Frest and Johannes 1992, as cited in COSEWIC 2003).

Depth limitations are unknown. In Canada, *G. angulata* has been observed in water less than 1 m deep to approximately 3 m deep although a single live specimen was collected in approximately 8 m of water from Vaseux Lake in 2009 (Pollard unpublished data). There have been no formal deep-water surveys conducted by SCUBA diving or other means (e.g., bottom trawl and dredging), and therefore it is possible that they inhabit greater depths. In the United States, this species has been found alive to depths of 20 m (COSEWIC 2003).

Habitat trends

The Okanagan basin has undergone large-scale modifications to its hydrological regime, as well as to associated lake shorelines and water quality over time. At least some of these changes have likely affected habitat quality and availability for *G. angulata*. Before European settlement, the Okanagan Valley bottom consisted of extensive wetlands associated with the tributaries flowing into the main basin lakes. From 1950 to 1958, most of the Okanagan River was channelized and dyked to prevent flooding, which severely altered the riverine habitat (Figures 6 and 7). Currently, the channelized sections have few or no key features of a natural river left, such as riffles, pools, undercut banks, islands, side channels, eddies or woody debris (Rae 2005). Three dams were established between Okanagan Lake and Osoyoos Lake to regulate domestic and irrigation water supplies, namely the Okanagan Dam at the outlet of Okanagan Lake, the Skaha Lake dam at the outlet of Skaha Lake and the McIntyre Dam at the outlet of Vaseux Lake (Rae 2005; Figure 8). There are also 17 weirs built to reduce turbulence at elevational changes within the Okanagan River (Tierrnan pers. comm. 2008; Figure 9). Each of these structures has an average elevation change of one metre and was built to slow the flow and control the grade (Toews and Allen 2009). The dams and weirs can limit or prevent upstream fish migration (Rae 2005; Walsh and Long 2006), which could limit *G. angulata* larval distribution reliant on host fish movement (see **Dams and weirs**).

Figure 6. Okanagan River draining into the north end of Skaha Lake, 1949. Photo: BC 800:31.

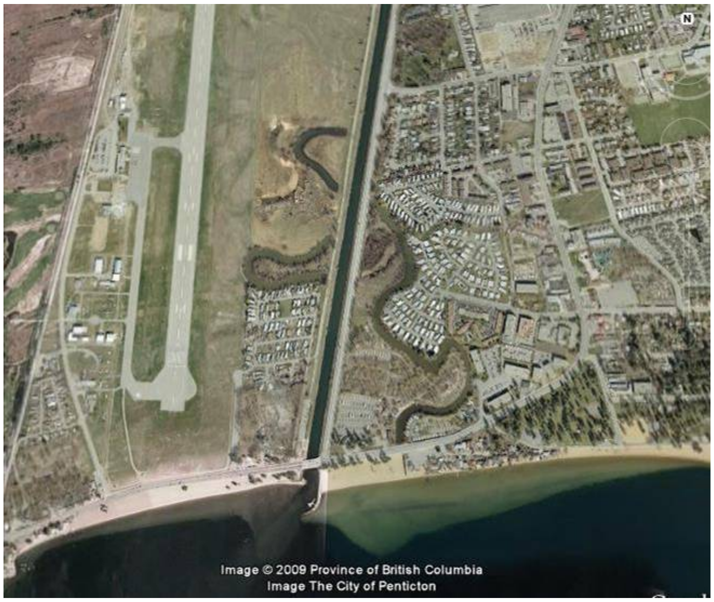

Figure 7. Okanagan River draining into the north end of Skaha Lake, 2009. Source: Google Earth.

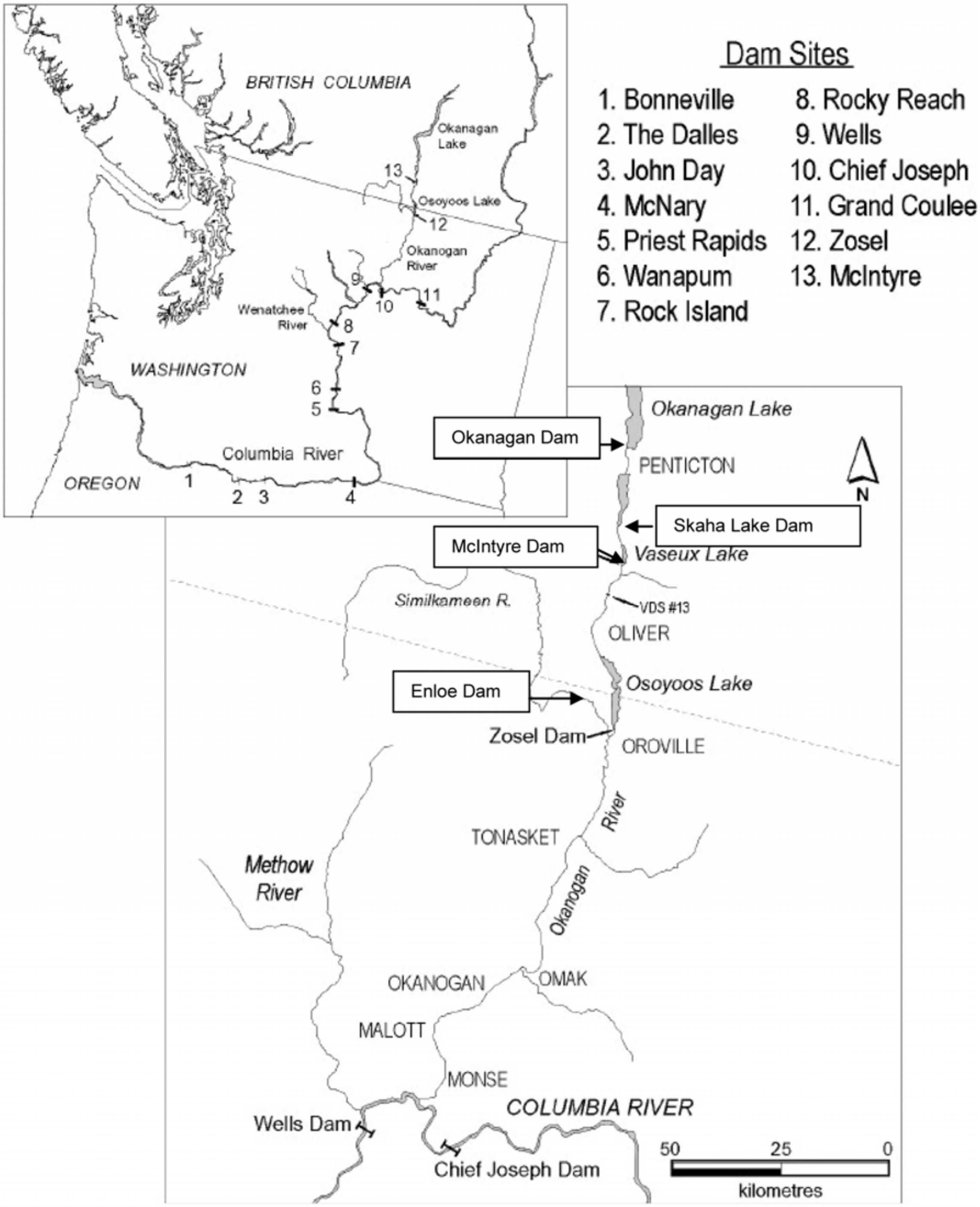

Figure 8. General sites of the Canada–U.S. dams (adapted from Hyatt *et al.* 2003).

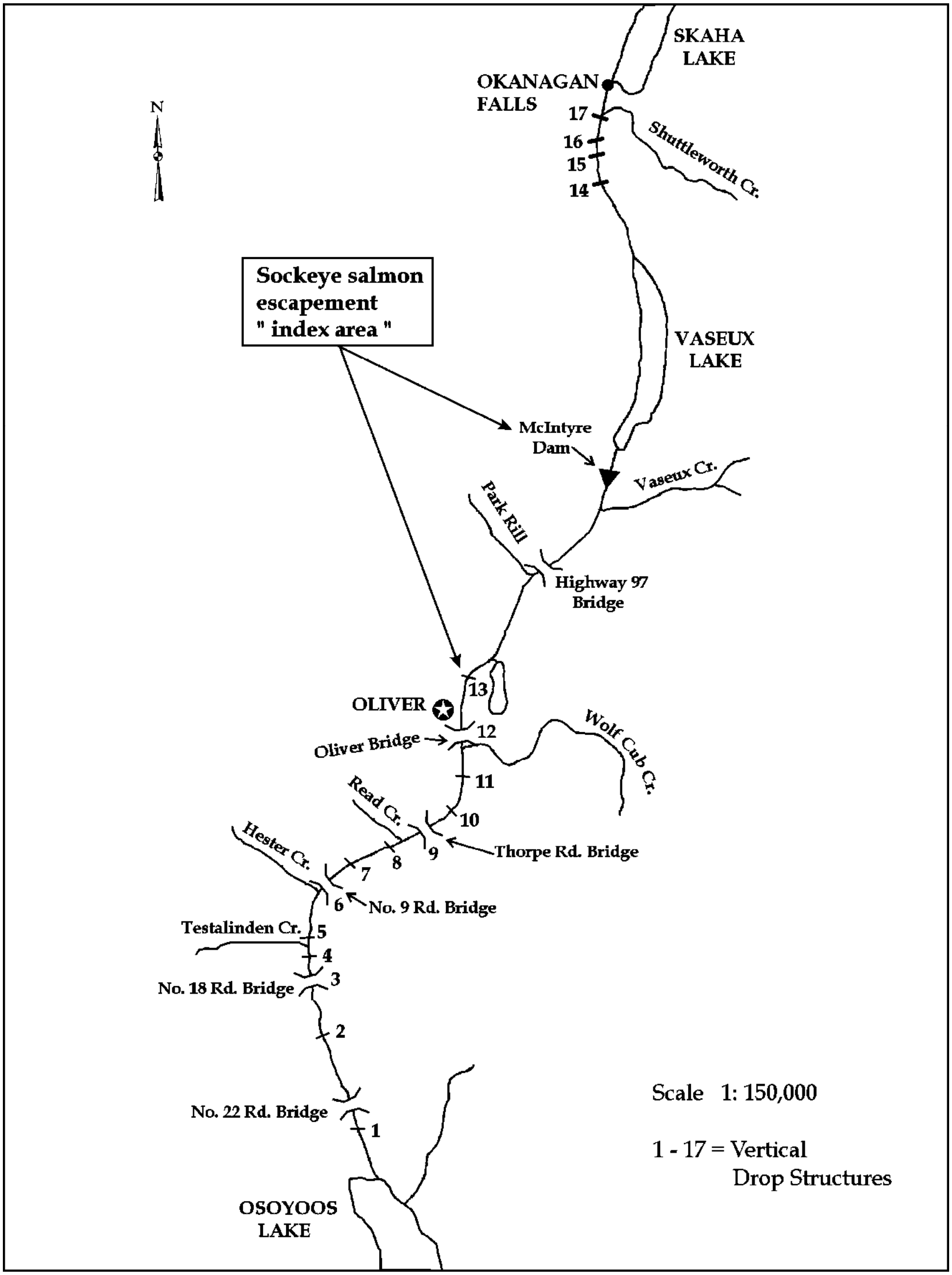

Figure 9. Weirs (vertical drop structures) in the Okanagan River from Skaha Lake to Osoyoos Lake (Hyatt and Rankin 1999).

Below the McIntyre Dam, south of Vaseux Lake, several oxbows (original river bends or meanders that represent about five to six kilometres of original channel) have been isolated from the main river channel due to channelization and now form horseshoe-shaped ponds (Rae 2005). They stem from the river channel, and water flows are regulated by inlets and outlets, altering the natural flow with the river. These oxbows have exceptionally warm temperatures (Tiernan pers. comm. 2008), which can interfere with temperature-dependent freshwater mussel reproduction (see **Life cycle and reproduction**), and contain introduced fish species such as Common Carp (*Cyprinus carpio*) and Smallmouth Bass (*Micropterus dolomieu*) (Tierrnan pers. comm. 2008) that impact mussels (see **Other introduced species**). Formal inventory has not been conducted in these areas, but *Anodonta* spp. have been incidentally observed in one oxbow (Tiernan pers. comm. 2008).

There is little natural river remaining. Channelization shortened the river from 61 to 41 km, resulting in a loss of area of 212–116 ha. Approximately 4 km (15 ha) or 7% of the river remains in an undyked, unchannelized state (Rae 2005). The natural section of the river runs from the outlet of Vaseux Lake south to the Highway 97 bridge. It is immediately downstream of the McIntyre Dam (Figure 8). Setback dykes allow the river to be semi-natural before the dykes close in again about 4 km from the outlet (Mitchell pers. comm. 2008). Much of the natural section was surveyed in August 2009, and several live mussels plus numerous shells were observed (Pollard unpublished data). These natural and semi-natural sections may be (or once have been) important habitat for *G. angulata*.

The shorelines and littoral zones of water bodies within the Okanagan basin have been altered by urban growth and agricultural development. Since 1940, the human population in the Okanagan basin has tripled every 30–40 years, reaching 300,000 in 2002 (Jensen and Epp 2002). As a result, humans have altered lake and river shores including by dredging to install docks and marinas, planting expansive orchards and vineyards, controlling invasive aquatic plants, installing lawns, and importing sand to create beaches (see **LIMITING FACTORS AND THREATS**). This development is expected to continue to increase in the future.

Suitable habitat may become available upon restoration of sections of the Okanagan River. Over a 2-year period starting in November 2008, the Okanagan River Restoration Initiative will realign a 1.2 km channelized section of the Okanagan River (north of Oliver) back into a 1.4 km meandering section (Matthews pers. comm. 2008). When this section was surveyed for fish (mussel inventory was incidental) in 2006, no mussels were detected (Dyer pers. comm. 2009), but this section could support *G. angulata* in the future if the host fish was also supported in this habitat.

In terms of habitat trends in the United States, this species is still considered fairly widespread but declining in terms of area occupied and number of sites and individuals; and habitat continues to be threatened (NatureServe 2008). The middle Snake River in Idaho is rapidly becoming eutrophic, due to agricultural runoff, fish farms, and urbanization along the river corridor (COSEWIC 2003). Much of the river is impounded behind a series of small dams; this is also detrimental to cold-water species such as *G. angulata*. The area has been declared “water-quality limited” by the Environmental Protection Agency (EPA) and the State of Idaho. Fine sediment influx, generally from sources listed above, is also a major problem. A landslide (1994) adjacent to the Snake River adversely affected some historic sites. Frest and Johannes (1999) summarize threats for this species at interior Columbia basin, California and Idaho sites. In the lower Columbia River region, threats to *G. angulata* include impoundments, continued siltation, and eutrophication. In Washington State, pesticide and herbicide runoff from orchards and other agricultural operations, as well as runoff from lumber mills, has led to increased nutrient loading in the Okanogan Physiographic Province (COSEWIC 2003). In the U.S. portion of the Similkameen River, suction dredge placer mining, a frequent activity in the river, caused mortality of *G. angulata* (Krueger *et al.* 2007).

Habitat protection/ownership

Habitat protection tools are available through various federal, provincial and local laws and regulations; regardless, the factors that threaten this species remain ongoing within the range of *G. angulata* (see **LIMITING FACTORS AND THREATS**).

Federal protection

The federal government fulfills its constitutional responsibilities for seacoast and inland fisheries through the administration of the *Fisheries Act*. The act provides Fisheries and Oceans Canada (DFO) with powers, authorities, duties and functions for the conservation and protection of fish and fish habitat (as defined in the *Fisheries Act*) essential to sustaining commercial, recreational and First Nations fisheries. The *Fisheries Act* contains provisions that can be applied to regulate flow needs for fish, fish passage, killing of fish by means other than fishing, the pollution of fish-bearing waters, and harm to fish habitat. Environment Canada has been assigned administrative responsibilities for the provisions dealing with regulating the pollution of fish-bearing waters while the other provisions are administered by DFO.

Under the *Fisheries Act*, aquatic molluscs, including freshwater mussels, are included under the definition of “fish”. However, it would have to be demonstrated that the mussel supports a fishery based on an appeal court decision (B.C. Appeal Court decision — R. *v.* MacMillan Bloedel [1984]; Clark pers. comm. 2009).

This species is currently listed as a species of Special Concern (Schedule 1) under the federal *Species at Risk Act* (Species at Risk Public Registry 2010) and a management plan for the species is currently in progress.

Approximately 60 km of the Okanagan basin shoreline is adjacent to several First Nations reserves including the Okanagan Band (Okanagan Indian Reserve (IR) #1; Priests Valley IR #6); Westbank First Nation Band (Tsinstikeptum IR #9 and #10); Penticton Band (Penticton IR #1) and Osoyoos Band (Osoyoos IR #1) (British Columbia Conservation Data Centre 2008). Limited inventory within the water adjacent to Indian Reserves (< 1 km), has not located *G. angulata*.

The Vaseux Lake Migratory Bird Sanctuary may indirectly protect *G. angulata* and its habitat within Vaseux Lake. Under the responsibility of the Canadian Wildlife Service, this sanctuary protects migratory birds and their habitat (Canadian Wildlife Service 2005).

<u>Provincial protection</u>

In British Columbia, *G. angulata* is found within Vaseux Lake Provincial Park, which is adjacent to a system of federal, Nature Trust and provincial conservation lands in the area. The park abuts the Canadian Wildlife Service managed Vaseux–Bighorn National Wildlife Area, which focuses on Bighorn Sheep and other species (Toews pers. comm. 2008).

Additional provincial habitat protection that may be applicable includes:

The *Fish Protection Act* provides legislative authority for water managers to consider impacts on fish and fish habitat before approving new licences, amendments to licences or issuing approvals for work in or near streams (B.C. Ministry of Environment 2008a).

The *Water Act* and *Water Protection Act* regulate activities in and around a stream and protect water resources in aquatic ecosystems, including wetlands and community watersheds (B.C. Ministry of Environment 2008b).

The *Forest and Range Practices Act* and regulations govern forest and range activities by licensees within the province, including those activities and impacts to riparian areas and species at risk (B.C. Ministry of Environment 2008c).

The *Environmental Management Act* provides a framework for the protection of human health and the quality of water, land and air in British Columbia. This regulates the discharge and introduction of waste into the environment, including sewage, industrial waste (e.g., pulp mills) and effluents (B.C. Ministry of Environment 2008d).

The *Park Act* provides for the establishment, classification and management of provincial parks and recreation areas dedicated to preservation of the natural environment for the inspiration, use and enjoyment of the public (B.C. Ministry of Environment 2008e).

Regional and municipal protection

The *Community Charter Act* and *Municipal Act* allow local governments additional powers to protect fish (molluscs are included under the definition of fish) and habitat (B.C. Ministry of Community Development 2008a,b).

BIOLOGY

Life cycle and reproduction

The life cycle and reproduction of *G. angulata* is believed to follow the general reproductive biology of freshwater mussels. Habitat temperature must be suitable for mussel survival, growth and reproduction (Strayer 2008). The life of a freshwater mussel can be separated into six stages (as summarized by COSEWIC 2003; Ruppert *et al*. 2004; Strayer 2008):

(1) Spawning: the male releases sperm into the water column, which is taken up by the female to fertilize the eggs held in the marsupial gills.
(2) Glochidial stage: within the gills, the fertilized eggs develop into larvae, called “glochidia”, over a period of weeks to months.
(3) Glochidial release: glochidia are expelled from the female mussel using a wide range of species-specific methods to attach to a host (e.g., displaying elaborate lures, depositing conglutinates (glochidia housed within mucilaginous packages) that resemble “fish food” and capturing and holding the fish to infest with glochidia).
(4) Encystment: the glochidia encyst (attach) onto a living host, where phagocytic cells in the larval mantle degrade and absorb the fish tissue for nourishment (adults are apparently not harmed by the glochidia, but fry may die from secondary infections). Here, the glochidia undergo transformation into juvenile mussels over several days to several months; during this time, dispersal via the host occurs.
(5) Excystment and juvenile stage: juveniles excyst (drop off) from the host, fall to the benthic substrate and gradually assume life as an adult. There is little known about the juvenile stage, but most live completely buried beneath the sediment. Juveniles are suspension feeders; however, they may deposit-feed as an alternative or supplement. This stage lasts from one to a few years depending on the species until they reach sexual maturity.
(6) Adult stage: upon sexual maturity, adults live at or near the surface of the sediment. Adults are primarily suspension feeders and can live up to several decades.

Mussels have two primary recognized reproductive strategies: (1) bradytictic, or long-term brooding, where spawning occurs in the summer and glochidia are retained by the female over the winter until they are released the following spring; and, (2) tachytictic, or short-term brooding where spawning occurs in the spring and glochidia are released that same season (Watters and O'Dee 2000). Recently, a third strategy, called "host overwintering" has been described, where glochidia overwinter on their host fish (Watters and O'Dee 2000). Reproductive patterns are unknown for *G. angulata* in Canada. Reproduction is affected by habitat variables such as water temperature and flow (Watters and O'Dee 2000; Hastie and Young 2003) and as a result, seasonal timing of reproduction within mussel species may differ both regionally and locally (Haley *et al.* 2007). In John Day River female *G. angulata* were gravid from early to late June (O'Brien 2008); in the Pit River, California periods of spawning and glochidial release occurred during late March/early April to mid-July (Haley *et al.* 2007). In Okanagan Lake, expelled conglutinates from a group of individuals were observed in June (see details below).

The specific method of host fish attraction and encystment is not known for *G. angulata* in Canada. In Okanagan Lake, approximately 5–10% of a dense group of mussels (1,000 mussels per 1,300 m^2) had expelled conglutinates that were confirmed to contain glochidia (Lee pers. comm. 2008; Figure 2). It is unknown how the glochidia of *G. angulata* attach to hosts, but feeding activity by fish on conglutinates may create a "plume" of glochidia that is quickly drawn into the gills of the fish during respiration (Haley pers. comm. 2008). *Gonidea angulata* conglutinates are likely more difficult to observe in faster flowing waters than lakes, as they appear to dissolve quickly (Haley pers. comm. 2008; O'Brien pers. comm. 2008). In the Pit and Fall Rivers in California, conglutinates were not observed, but glochidia were distributed diffusely in the water column. In this situation, glochidia attach as the fish swim through infested waters (Haley pers. comm. 2008).

The lifespan of *G. angulata* was previously documented to be 20–30 years based on growth ring counts (COSEWIC 2003). More recently, a lifespan of 60 years was reported (Frest and Johannes 2006), but the method of determining age was not provided. Counting external growth bands on shells underestimates the ages of older specimens and is of limited use for determining age of unionids (Neves and Moyer 1988). In contrast, a recent study determined that mark–recapture studies greatly over-estimate age, particularly where most individuals are of a large size, and recommended the use of internal growth rings (Haag 2009). Vannote and Minshall (1982) report a maximum age for *G. angulata* from Salmon River, Idaho to be 24 years, using growth rings. Thus, an estimate of 20–30 years seems more plausible until more information is available. If sexual maturity is reached by three years, age distribution is uniform and the maximum age is considered 30 years it can be estimated that the average age of an individual breeding *G. angulata* is 15 years.

Once attached to a fish, glochidial survival is typically low, ranging between 10 and 18,000 individuals per billion glochidia that survive to the one to two year stage in the few taxa for which estimates have been made (Jansen *et al.* 2001). There is evidence that suitable host fishes can develop resistance to glochidia after multiple infections; however, the basis of this resistance is not fully understood (Strayer 2008).

Predation

Predation on *G. angulata* in North America has not been documented for any life cycle stage. From glochidia to adults, predators of freshwater mussels may include zooplankton, crayfish, insect larvae, aquatic bugs (Hemiptera), beetles, aquatic snails, fish, birds, turtles and mammals. In the laboratory, microturbellarians, which are abundant in lakes, streams and rivers, are voracious predators of glochidia and small juvenile mussels; however, nothing is known about their predation in nature (Strayer 2008 and references therein). In southern B.C., consumption of freshwater mussels (species unknown) by River Otters (*Lontra canadensis*) and Common Muskrats (*Ondatra zibethicus*) has been documented (Moore and Machial 2007; Mitchell pers. comm. 2008). Raccoons (*Procyon lotor*) are also commonly reported to consume large quantities of mussels (Strayer 2008). Skunks also may eat mussels and water birds may also scavenge for dead mussels when water levels are low (Nedeau *et al.* 2005). Gulls were observed predating *G. angulata* at Okanagan Lake (Ray Lauzier pers. comm. 2009). Parasites and diseases can also affect the composition of mussel communities (Strayer 2008). The extent to which predators and parasites are a limiting factor for *G. angulata* is not known.

Freshwater mussels are known to be harvested by humans, as shells have been found at First Nations archaeological sites in southern B.C. Archaeologists concluded that freshwater mussels did have some importance as a food resource and/or a source of material for tools and ornamentation for Aboriginal peoples (Lindsay 2000). It is not known if or how harvesting of freshwater mussels has affected *G. angulata*. Presently, the level of harvesting of freshwater mussels for human consumption or ornamentation is unknown. There is at least one report of an individual collecting mussels (species unknown) for consumption near Jaffray, in southeastern B.C. (Jamieson pers. comm. 2008).

Physiology

Relatively little specific information is available for *G. angulata*. It appears to be somewhat stenothermal, favouring cold-water oligotrophic habitats (Frest 1999; Frest and Johannes 2001; as cited in COSEWIC 2003). There are historic records of this species having been found in Osoyoos Lake (but not live animals) and a few other productive water bodies in the U.S.; therefore, physiological tolerances may be broader than originally thought.

This species has a strongly angular, wedge-shaped shell, and the foot is commonly positioned at a right angle to the shell ridge which provides a very strong anchor (Vannote and Minshall 1982). Like other mussels, *Gonidea angulata* is well adapted to aggrading rivers due to its well-formed distal inhalant and exhalant siphons and to its ability to bury most, if not all, of its shell in sediments without affecting feeding (Vannote and Minshall 1982). The heavy shell also is well suited to riverine conditions. However, if complete burial of an adult occurs, death can result (see **Channelization of the Okanagan River**). Freshwater mussels are filter feeders; feeding may be limited under temperature extremes, during periods of relatively high sediment influx, or to avoid pollution or other habitat condition surges (COSEWIC 2003).

Erosion of shells can cause mussels to become susceptible to shell-dissolving acids (Harman 1974, as cited in Watters 2000), and can increase their risk of predation, exposure to pollutants, parasitism and disease (Kinney pers. comm. 2008).

Dispersal/migration

There are no data on the dispersal abilities of *G. angulata* in Canada. Freshwater mussels are passively dispersed as glochidia by host fishes. Not only is dispersal based on host fish movement but the host fish is required for the continued survival of the mussel species. All available habitat may not be occupied, and range may vary in size, depending upon the number and dispersal potential of the host fishes (COSEWIC 2003).

Repeat visits to some U.S. Okanogan sites seem to indicate little or no seasonal or life stage movement of post-glochidial forms within this species, even in relatively shallow streams (COSEWIC 2003). Adult specimens in the Little Granite Reservoir showed little sign of movement even as the reservoir was dewatered, effectively dying in place. As with many large freshwater mussels, juveniles and young specimens seem more active than older individuals that appear to have limited movement. Displaced individuals have been observed to re-orient and rebury themselves (COSEWIC 2003). Vannote and Minshall (1982) found that *G. angulata* from the Salmon River, Idaho, moved vertically (5 cm/hr at 20°C) under both sudden (30 cm/hr) and gradual (1–10 cm/hr) experimental burial by sediments. Krueger *et al.* (2007) suggest that these rates may differ with burial depth, substrate size and mussel size. Burrowing mussel species also undergo vertical migrations that may be in response to day length or to avoid extreme temperatures and predation (Perles *et al.* 2003 and references therein). *Gonidea angulata* does not appear to migrate during the breeding season (COSEWIC 2003); however, Amyot and Downing (1998) found that individuals of another mussel, *Elliptio complanata,* moved closer together during this time. *Gonidea angulata* appears unable to readily colonize new habitats, such as borrow pits, highway lakes, or dredged river sections (COSEWIC 2003).

Interspecific interactions

It is essential that *G. angulata* glochidia parasitize a host fish. During this stage, glochidia metamorphose into juveniles before dropping off the fish to the benthic substrate. In Canada, host fishes have not been studied; thus, it is not known which species are responsible for dispersal.

Multiple species of fish have been confirmed as hosts in the U.S., and it is possible that there are multiple hosts in Canada. In Oregon, the Torrent Sculpin (*Cottus rhotheus*) is an unconfirmed host in the Middle Fork John Day River although it should be noted that salmonids were not assessed (O'Brien pers. comm. 2008). This same species is native to B.C. and is found in the Kootenay River and Similkameen River but is absent from the Okanagan basin (McPhail 2007). In California, Hardhead (*Mylopharodon conocephalus*), Tule Perch (*Hysterocarpus traski*), and Pit Sculpin (*Cottus pitensis*) were confirmed host fish species (Haley *et al.* 2007), none of which are found in B.C. However, two unconfirmed hosts from the same study, the Rainbow Trout (*Oncorhynchus mykiss*), which is native to California, and the Black Crappie (*Pomoxis nigromaculatus*), which is non-native in California, are potential hosts in B.C., as they are found within the range of *G. angulata.* The Rainbow Trout is a native species in the Okanagan and Kootenay River drainages, and the Black Crappie is a non-native species that occurs within Osoyoos Lake (McPhail 2007). California researchers suggested that the Pit Sculpin (*Cottus pitensis*) may be the most important host, as more juveniles transformed on sculpin than on other fish species (Haley pers. comm. 2008). Although the Pit Sculpin is not found in the Okanagan basin, a number of other sculpin species are, including Slimy Sculpins (*Cottus cognatus*) and Prickly Sculpin (*Cottus asper*). It is reasonable to speculate that sculpins may be hosts in B.C. as well.

In terms of diet, unionids were once considered suspension feeders of phytoplankton, zooplankton and particulate detritus but more recent work suggests that they may also feed on suspended bacteria (Strayer 2008). Adult unionids filter food out of the water column, but may also deposit-feed on benthic materials similar to juveniles (Strayer 2008). Rates of filtration vary according to different environmental conditions, species, and life stage, thus resulting in the potential for interspecific competition among unionids and other filter feeders such as the introduced dreissenid mussels (Strayer 2008). No specific dietary information for *G. angulata* is available.

If dreisssenid mussels are introduced into the Okanagan basin and proliferate as has been the case elsewhere, it is expected that the *G. angulata* would experience severe biofouling, in addition to competition for food (see **LIMITING FACTORS AND THREATS, Dreissenid mussels**).

Adaptability

There have been drastic anthropogenic changes to water bodies within the range of *G. angulata*, due to urban and agricultural development and the creation of dams and weirs (see **Habitat trends**). There have been no studies to indicate if or how this species has adapted to factors resulting from these changes. There has been no attempt to artificially rear or transplant *G. angulata* in Canada.

POPULATION SIZES AND TRENDS

Sampling effort

Historical surveys

There are fourteen "historical" records of *G. angulata* prior to and including the 2003 COSEWIC report (Table 1). None of the records contain information on sampling methodology or search effort. Eleven of the fourteen records are from museum specimens dating from 1906 to 1991 and collected from the Okanagan basin, including the Okanagan River, Skaha Lake, Vaseux Lake and Osoyoos Lake. Of the remaining three records, one is reported from the Kootenay River (date unknown), one is a museum specimen attributed to Vancouver Island (1890s) and one is an observation (2002) from Park Rill in the Okanagan Valley.

Recent surveys

From 2005 to 08, surveys by the B.C. Ministry of Environment targeted *G. angulata* within lakes, streams and rivers across southern B.C. For convenience, the survey areas have been divided into five sections, including (1) Vancouver Island (Bamfield and south), (2) Similkameen basin (Princeton south to the Canada/U.S. border), (3) Okanagan basin (Vernon south to Osoyoos Lake), (4) Kootenay Boundary (Kettle River east to Christina Lake) and (5) Central and East Kootenays (Arrow Lakes east to Kootenay River) (Figure 5). At least 430 person-hours were spent searching 179 sites along a minimum shoreline (linear) distance of 90.8 km (Table 2). The total number of hours and shoreline distance for each section is conservative, as total search effort and distance searched were not recorded at all sites. *Gonidea angulata* was observed only within the Okanagan basin.

Inventory was conducted by visually inspecting the benthic substrate while wading and/or snorkelling throughout the survey area; surveys from a boat were used on two occasions (see *Sampling effort by region*; Okanagan basin). Sites chosen were based on accessibility from shore and advice from regional Ministry of Environment staff, dive shops, naturalists and local residents. The length of time spent searching in the water and the size of the survey area was based on water temperature (e.g., how long surveyors could remain in cold water), ability to observe the substrate (e.g., water clarity, depth) and safety of the surveyors (e.g., to avoid boat traffic). Searching was also conducted by walking along the shore to collect empty shells. Data collected included GPS coordinates, total search effort, total area searched, abundance and habitat description. Inventory involving excavation of the substrate was not conducted.

Provincial volunteer mail-out survey

A province-wide, volunteer-based, freshwater mussel mail-out inventory project (modelled after Smith *et al.* 2005) was initiated by the B.C. Conservation Data Centre (CDC), Ministry of Environment. In August and September of 2008, the CDC mailed out approximately 100 information packages to individuals who had contact with freshwater habitat. The package included information on freshwater mollusc species within B.C., a form to record data and a box to mail shells back to the CDC for identification. For contacts within southern B.C., a poster with additional information and photos of *G. angulata* was included. As of November 2008, volunteers located *G. angulata* shells from one previously unknown site at the north end of Okanagan Lake (British Columbia Conservation Data Centre 2008).

Sampling effort by region

Vancouver Island

There is one museum specimen labelled "Vancouver Island" that dates from approximately 1890 (Appleton pers. comm. 2008); it is not known if this specimen has been mislabelled, or if it represents a previous population on the island or was transported here by humans. There are many historical museum records of freshwater mussels from Vancouver Island but none for *G. angulata* (Lee and Ackerman 1998a,b).

During recent surveys on southern Vancouver Island, at least 13.6 person-hours were spent searching eight sites along a minimum shoreline (linear) distance of 5.3 km (Table 2). Surveys were conducted by snorkelling, wading and walking along the shoreline to look for shells. No *G. angulata* were detected. The surveys were limited and conducted opportunistically as the highly questionable validity of this record did not warrant further commitment.

Similkameen basin

Gonidea angulata occurs within the U.S. portion of the Similkameen River (Krueger *et al.* 2007). Inventory within the Canadian portion of the river was conducted in 2006, 2007 and 2009. At least 13.2 person-hours were spent searching seven sites along a minimum shoreline (linear) distance of 4 km of the Similkameen River (Table 2) prior to 2009. Surveys were conducted by snorkelling, wading and walking along the beach to look for shells. Two of the surveys in 2006 focused on fish inventory and mussels were looked for secondarily. The water was also higher than average in 2006. Additional, informal interviewing of a long-term, shoreline resident of the area, approximately 1 km north of the border, indicated they had never observed live mussels or shells in the immediate area. Most recently (September 2009), efforts to survey for *G. angulata* within one kilometre of the international border included two sites and five additional person-hours. Although another riverine unionid (*Margaritifera falcata*) was observed at both sites, no *G. angulata* were found.

<u>Okanagan basin</u>

Recent surveys (Figure 5) have shown that the range of *G. angulata* is more expansive than previously known, due to the discovery of live mussels in Okanagan Lake (Table 3; Figure 10). Surveys have also confirmed historical records within Okanagan River, Skaha Lake and Vaseux Lake (Table 1, 3). Future inventory should focus on Osoyoos Lake to determine if *G. angulata* is extant (the last observation was of empty shells in 1990) and throughout the remaining natural and semi-natural sections of the Okanagan River that have not yet been sampled.

Table 3. Number of live *Gonidea angulata* observed during recent surveys (2005–08).

Survey Site	Date	No. of live *G. angulata* observed
Okanagan Lake; Illahie Beach RV Park, Summerland	2005-08-15	14
Okanagan Lake; Dog Beach, Summerland	2006-03-24	14
	2007-06-28	1000+
Okanagan Lake, Kinsmen Regional Park, Summerland	2006-03-27	4
	2006-06-01	100+
	2006-07-13	100+
Okanagan Lake, Crescent Beach, Summerland	2006-03-27	15
Okanagan Lake, Houseboat Beach, Summerland	2006-03-27	2
Okanagan Lake; north of "Houseboat Beach", Summerland	2008-08-20	5
Okanagan Lake (east side); 3 Mile Point Dog Beach, north of Penticton	2006-07-24	8
	2007-07-10	56
Okanagan River (south of Skaha Lake) south of Prov. Park	2007-06-27	200
Skaha Lake; south end, Kettle Valley Railway (site A)	2008-07-19	2
Skaha Lake; south end, Kettle Valley Railway (Site B)	2008-07-19	1
Vaseux Lake Provincial Park	2006-07-11	2
	2007-07-07	22
Okanagan River (upstream of Road 22 bridge)	2007-07-07	19
Okanagan River, South of Skaha Lake	2008-07-19	1

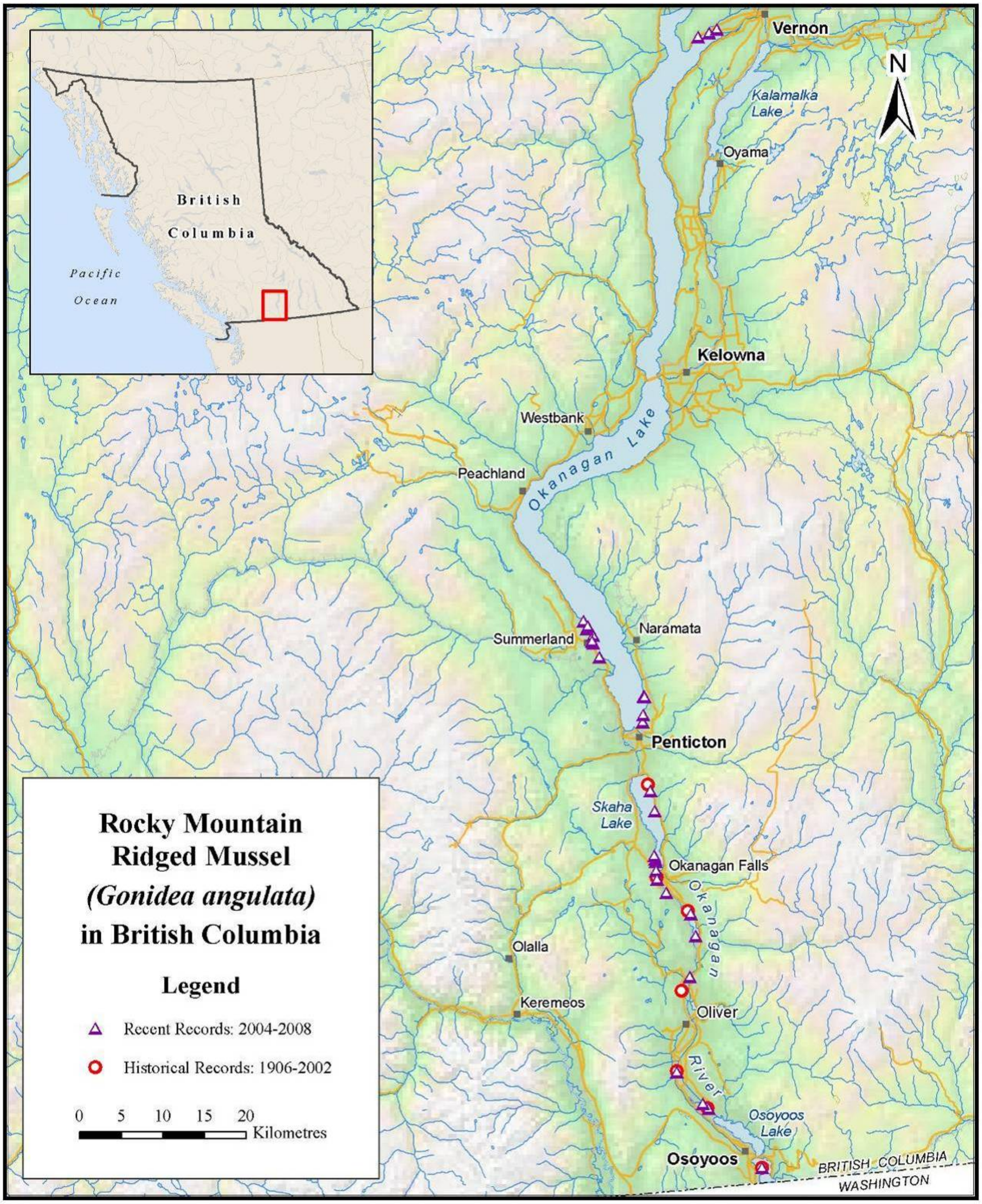

Figure 10. Historical (1906–2002) and recent (2004–08) records of *Gonidea angulata* in British Columbia. Map prepared by B. Woods, B.C. Ministry of Environment.

At least 147.4 person-hours were spent searching 86 sites along a minimum shoreline (linear) distance of 31.5 km within the Okanagan basin (Table 2) prior to 2009. A significant portion of the suitable habitat within the Okanagan basin has been searched, including most that was accessible (Figure 5). While only approximately 10% of Okanagan Lake shoreline has been surveyed, much of the unsurveyed shoreline (especially on the east side of the lake) is represented by steeply sloped banks of large angular boulder and bedrock which is unlikely to provide burrowing substrate (Pollard pers. obs.). Surveys were primarily conducted by snorkelling, wading and walking along the shoreline to look for shells. Of the 147.4 person-hours, 21 were spent visually scanning the benthic substrate from a boat (using a pole with a net to identify mussels) and five person-hours were spent using a remote underwater camera (Heron pers. comm. 2008). Formal SCUBA diving surveys were not conducted.

In August 2009, additional surveys were conducted in the Okanagan River downstream of McIntyre Dam (below Vaseux Lake) where an unchannelized section remains. Additional surveys via boat and beach walking were also conducted on Osoyoos Lake in August and September 2009, as well as at several previously surveyed sites in Okanagan Lake in July to October 2009 via wading and snorkelling to better qualify abundance, as well as survey a number of new sites on the east side of the lake only accessible by boat. Although total effort has not been calculated to date, it involved several days of snorkelling and wading hours conducted by two to six individuals at a time (Pollard unpublished data).

Kootenay Boundary

There have been no reports of *G. angulata* occurring in this area historically or with recent search efforts. This area was included in the surveys as it is part of the Columbia basin. An unverified historic record exists for Kootenay River (see below).

At least 9.3 person-hours were spent searching 15 sites along a minimum shoreline (linear) distance of 2.1 km within the Kootenay Boundary area (Table 2). Surveys were conducted by snorkelling, wading and walking along the shoreline to look for shells.

Central and East Kootenays

Only one record exists for this area (“Kootenay River” [Clarke 1981]; see **Canadian range**). During 2007 and 2008, species-targeted surveys focused within lakes, creeks and rivers within the central and east Kootenays (including Kootenay River); however, no *G. angulata* were detected. Inventory in this area was conducted within the summer months when water levels are high. Mussels may be more visible at low water levels, as they likely do not migrate with fluctuating water levels. Future inventory should focus in this area when water levels are the lowest; for example, Kootenay Lake levels are lowest during late March to late April (Fortis BC 2008).

At least 62.6 person-hours were spent searching 63 sites along a minimum shoreline (linear) distance of 9.7 km within lakes, streams and rivers. Surveys were conducted by snorkelling, wading and walking along the shoreline.

Abundance

Four of the historical museum specimens (1972–82) were known to have been collected alive (Vaseux Lake and the Okanagan River); the greatest number was four individuals collected at any one time (Table 1). Of the 86 sites surveyed from 2005 to 2008, live *G. angulata* were observed at 13 (Okanagan Lake, Okanagan River, Skaha Lake and Vaseux Lake). The ages of individuals were not determined. Most survey sites where the species was found contained 1–10 live individuals; however, there were two sites with over 100 and one site with over 1,000 individuals (Table 3) including two sites in Okanagan Lake and one in Okanagan River at Okanagan Falls. Thus, not taking into account historical records, and noting that not all suitable habitat was searched, there are at minimum 1,187 live individuals in Okanagan Lake, 220 in the Okanagan River, three in Skaha Lake and 22 in Vaseux Lake, for a minimum of 1,432 live *G. angulata* in the Okanagan basin population.

Densities appear to vary considerably and individuals appear to be clumped. During recent surveys, live individuals were observed as far apart as several metres to more than 1,000 m in an area of 1,300 m^2 (0.76 per m^2), with densities in the latter group of up to 20 per m^2. Note that the most recent population estimate survey conducted in August 2009 using stratified sampling of a 2,525 m^2 area at this same site indicated that approximately 1,200 individuals (almost all > 60 mm long; few young animals) were present. In Washington State, as much as 10 m or more separated individual *G. angulata* (0.04 individuals per m^2) in the Lower Granite Reservoir, and densities of approximately 16 individuals per m^2 were observed in 1988 and 1991 in the Okanogan River, Washington (T.J. Frest, unpublished data). In the Salmon River Canyon, Idaho, densities of *G. angulata* ranged from 5.5 to 183 per m^2, depending on the composition of the substrate (Vannote and Minshall 1982). In *Elliptio complanata*, low densities may reduce reproductive success, as females need to be close enough to males to filter sperm from the water column (Downing *et al.* 1993). In terms of recruitment, it is currently impossible to determine at this time whether or not recruitment is occurring, and to what extent. Size variation was observed in Okanagan Lake where densities were greatest; however, very few shells less than 50 mm in length were observed (Pollard unpublished data). Substrate sifting has not been conducted; this is required to confirm the presence of juveniles which may remain buried in interstitial areas.

In considering these observations as they relate to possible abundance estimates, it is noted that almost all surveys in B.C. occurred during warm summer months when mussels are most active and likely breeding. For burrowing mussel species generally, researchers have reported that up to 90% of the population may be below substrate (i.e., during winter), and most juveniles remain buried in substrate (Balfour and Smock 1995). These researchers also noted that most mussels (80%) were on the surface when glochidia are released.

Not all shoreline sections of Okanagan Lake, as well as the Skaha, Vaseux, and Osoyoos lakes, have been surveyed due to inaccessibility. Additionally, presence at depths beyond what is accessible via snorkelling and wading cannot be ruled out until SCUBA surveys have been completed, particularly in Okanagan Lake. For this reason, it is difficult to estimate accurately the size of the Canadian population of *G. angulata* at this time.

Fluctuations and trends

Changes in population size and density within the Okanagan basin cannot be assessed, as there are insufficient historical data. Up until 2002, only 14 records existed for this species with a maximum of four specimens collected and recorded from a survey site. Recent observations and species-targeted inventory has increased the total number of records to 51, with observations of more than 1,000 mussels at one survey site (Table 3). Increases in numbers of live *G. angulata* at a single survey site at subsequent dates (Table 3) cannot be attributed to increases in populations, as survey methods, water conditions, burial depth of mussels and search effort were not consistent at each site. Although more data are needed to analyze current fluctuations and trends, historically (1950s), habitat for this species was highly modified by humans and the population likely declined during that period (See **LIMITING FACTORS AND THREATS**).

In terms of qualitative observations, the most recent surveys conducted in August 2009 reported two sites where significant numbers of empty shells were observed with very few live *G. angulata* present. In particular, a number of large empty shells were observed at a small site in Vaseux Lake where only three large live mussels were noted. Most obvious, however, was the layering of many large intact shells wedged in the submerged cobble substrate along the west bank of Okanagan River in the unchannelized (oxbow) section below McIntyre Dam suggestive of a once large population here. Of the 500 m surveyed in this stretch, only 12 large live specimens were observed (Pollard unpublished data). It is not known how long shells stay intact after the animal dies and this probably depends on water chemistry and abrasive action.

Rescue effect

Within its historic U.S. range, *G. angulata* exists in scattered populations presumed to be declining. In the middle Snake River, Idaho, finds of dead shells greatly outnumber living individuals and sizable stretches of the river now lack living specimens.

Furthermore, some waterways from which living specimens have been reported (e.g., the Yakima and Wenatchee Rivers, Washington) also now lack living specimens (COSEWIC 2003). Some rivers within the range of *G. angulata* may lack historical records due either to absence of early collections or lack of the species during historical collections, so that modern absence may not reflect change from historical status (e.g., Sanpoil River, Washington). In the Okanogan River in Washington and elsewhere, Frest (pers. obs.) noted many populations in which recent recruitment appeared not to have occurred, suggesting degradation from former status. Frest and Johannes (2001) termed it "locally common but decreasing" and suggested careful monitoring of extant populations for eventual protection in Idaho.

The Canadian range of *G. angulata* only appears to extend into the Okanagan basin where the transboundary Osoyoos Lake straddles the Canada/U.S. border. Zosel Dam is at the outlet of the lake in the U.S. and is operated to allow fish passage (Rae 2005). At the outlet of the lake, the river continues south, before reaching the Columbia River in Washington State (Figure 8). Given that the mussel occurs in the U.S. portion of the Okanagan River and Zosel Dam enables upstream fish passage, recolonization may be possible. It is, however, unclear if Osoyoos Lake supports *G. angulata*. Furthermore, Washington populations face a number of threats and are considered imperilled (S2) (see **HABITAT**), thus, chances for immigration and rescue are expected to be low. Further, as *G. angulata* exists primarily in creeks and rivers in the U.S. and many of host fish in the U.S. are riverine species, it is unknown if immigrating populations would be able to adapt to lake habitat in Canada. If immigration occurred via Osoyoos Lake, it is unknown to what extent the dams and weirs located throughout the Okanagan basin would prevent further movement north.

Gonidea angulata is confirmed within the U.S. portion of the Similkameen River which is a tributary to the Okanogan River. The Enloe Dam bisects the Similkameen River approximately 14 km above its confluence with the Okanogan River and is a barrier to anadromous fish (Figure 8). Before the dam was built, a natural barrier existed, thus sea-run fish have never had access to the upper Similkameen (Rae 2005; Arterburn *et al.* 2007); however, *G. angulata* exist both above and below this dam (Krueger *et al.* 2007) and could provide a source to the Okanagan River as described above. The Similkameen River south of the international border appears to have large populations of *G. angulata* (Kreuger *et al.* 2007), and above Enloe Dam there are no obvious barriers to host fish movement. No *G. angulata* have, however, been reported in the Canadian portion of the Similkameen River to date.

Finally, there are no reports of *G. angulata* in the Pend d'Oreille River, which crosses from British Columbia into Washington State (spelled "Pend Oreille River" in the U.S.). Immigration into Canada from the Kootenai River (in the U.S.) is possible, but only if a population exists; there are historical records within Idaho and possibly Montana, although it was not detected in Montana in recent surveys (Nedeau 2005; NatureServe 2008). Rescue from this area is unlikely.

LIMITING FACTORS AND THREATS

Dreissenid mussels

Loss and degradation of habitat by channelization and the creation of dams and concrete weirs within the Okanagan River have likely been the historically most significant threat to *G. angulata* in Canada. However, the spread into the Okanagan basin of invasive dreissenid mussels, namely Zebra Mussel and Quagga Mussel, while yet to be manifested, is the most serious threat to *G. angulata*.

Both species of dreissenid mussels originate from the Caspian Sea but in the late 1980s became established in eastern North America, including the Great Lakes region in Canada. Once established, these mussels frequently develop into dense formations that infest lakes or rivers and have had devastating impacts on native unionid communities. Effects include biofouling leading to restriction of valve operation (thus restricting feeding, smothering siphons and impairing movement), shell deformity, depositing of metabolic waste onto unionids, and competition for food (Ricciardi *et al.* 1998; USGS 2008). These infestations have resulted in extirpations and massive declines in populations of numerous native unionid species in the Great Lakes region (Schloesser *et al.* 1996).

To date, the Quagga Mussel has expanded as far west as west-central California, Utah, Nevada, and Arizona, likely transported across land attached to boats and trailers (Britton and McMahon 2005; Hickey 2010; Mackie and Claudi 2010). A risk assessment of water quality in Okanagan Lake to dreissenid mussel infestation performed by Mackie found a high potential for infestations of Zebra and Quagga mussels in five out of six parameters. He concluded that there is a high risk of dreissenids not only surviving in the lake but also developing massive infestations. Quagga Mussel is now established in Lake Mead, Nevada (Figure 11). Under cool, humid conditions, these mussels can remain alive for 10 days out of water under favourable conditions (McMahon *et al.* 1993). Although the closest, established population to B.C. is in Utah, at least 12 reports of boats being trailered on land from known infested waters in Montana and Idaho to southern B.C. have been documented in the past 10 years (USGS 2008; Herborg pers. comm. 2009; Figure 11). Since 2007, there have been at least three incidents where B.C. Ministry of Environment staff were alerted by Washington Fish and Wildlife staff to dreissenid mussel-infested boats travelling into B.C. (Herborg pers. comm. 2009). A recent predictive analysis (Whittier *et al.* 2008) based on calcium levels in lakes of B.C. puts Okanagan basin water bodies at high risk of invasion (Herborg pers. comm. 2009). Given that it took approximately two decades for dreissenid mussels to spread from eastern North America to California, it seems reasonable to expect an introduction into B.C. waters within the next 10 years based on ongoing rate of spread. Although the western U.S. states are now implementing some aggressive measures to prevent further spread (including decontamination stations and identification tools for border patrols), no similar mechanisms exist in B.C. or other provinces to prevent westward spread. Measures to curb the spread of dreissenids in the U.S. failed to prevent their spread in a U.S. National Recreation Area (Hickey 2010).

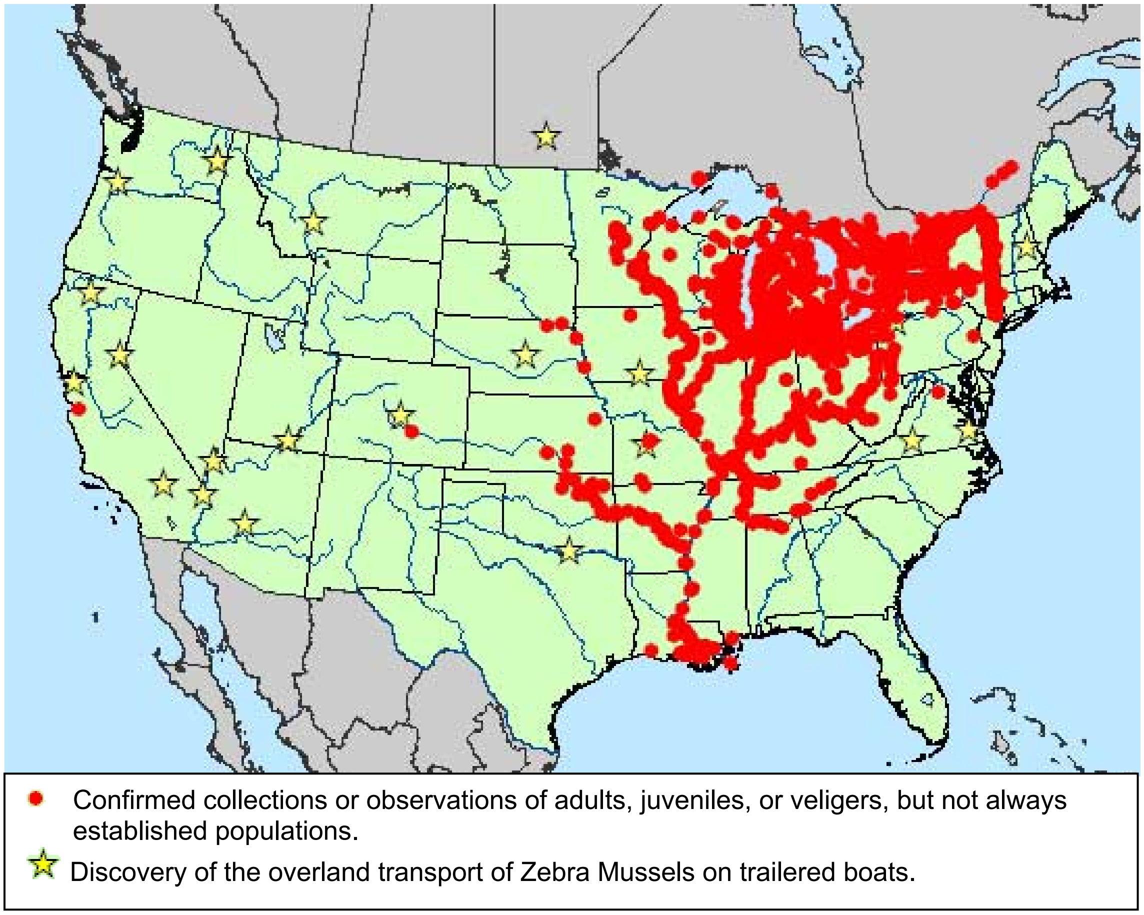

Figure 11. Zebra Mussel distribution in North America as of 2008. Map from the U.S. Geological Survey website (USGS 2008). Note that this map does not include recently reported boats crossing the B.C. border.

Channelization of the Okanagan River

Physical disturbance to freshwater mussels can have sub-lethal detrimental effects, including early release of glochidia and failure to reproduce (Hastie and Young 2003). Because of the long lifespan of mussels, effects of human disturbance may take years or decades to be fully expressed as changes in mussel populations (Strayer 2008). Because *G. angulata* is probably long-lived, and there have been no direct studies on limiting factors or threats to this species in Canada, it is not known to what extent past or current disturbances have affected or are currently affecting *G. angulata.* In Canada, *G. angulata* is not threatened by direct exploitation, but by historic and ongoing loss and/or degradation of its habitat, caused by channelization and damming of rivers, development of lake and river shores, pollution, and introduced species.

Dredging and channelization of the Okanagan River likely has been and remains a significant threat to *G. angulata*. During the process of channelizing a river, mussels caught in the path of the dredge are destroyed (Watters 2000). In the Okanagan River, dredging occurred in the 1950s as part of a flood management initiative; however, it is unknown to what extent mussels in the river were damaged. Silt and other suspended solids generated by channelization can travel downstream, smothering mussels and eroding shells (Watters 2000). Complete burial of adult freshwater mussels by silt or gravel has been shown to cause mortality (Krueger *et al.* 2007 and references therein). Within the Similkameen River, Washington, burial of *G. angulata* by dredge tailings killed 6–13% of a test population (Krueger *et al.* 2007). In contrast, Vannote and Minshall (1982) found that *G. angulata* was able to move vertically under both sudden and gradual burial by sediments in 20°C (see **Dispersal/Migration**); undoubtedly, movement would be hindered at reduced water temperatures. Variation in these outcomes may be due to differences in burial depth, substrate size and mussel size (Krueger *et al.* 2007).

Dredging and channelization reduce habitat heterogeneity and aquatic diversity (Watters 2000); this may affect both mussel and host fish. Channelization alters the hydrology of rivers, usually resulting in increased water velocities leading to scouring and erosion. In particular, scouring in both channelized and unchannelized sections of the Okanagan River is significant during high flow periods when lake levels are being regulated to control flooding (Jensen pers. comm. 2009; see also **Dams and weirs**). Scouring and high flows will reduce available burrowing materials for mussels and may prevent settlement of juveniles as well as fertilization, particularly in channelized sections where velocity refugia are limited. Such conditions may also affect the distribution of host fish. Host fishes for *G. angulata* remain unknown; however, loss of host fish has been implicated in the decline of mussels (Watters 2000 and references therein).

Creation of the dykes that line the channel of the Okanagan River removed 85% of streamside vegetation, resulting in increased water temperatures in some sections of the river (Rae 2005). High temperatures can kill mussels and affect reproductive success by controlling the release of glochidia, decreasing the length of time that glochidia are viable and affecting growth rates (Strayer 2008). Changes in temperature may also affect potential host fish migration; for example, salmon must delay entry into the Okanagan River to spawn by holding in Osoyoos Lake until temperatures fall (Rae 2005).

Dams and weirs

Dams and weirs are barriers to potential host fish movement, and associated water level fluctuations may affect both mussels and host fish. Dams and weirs are located throughout the Okanagan basin and into the U.S. (Figures 8 and 9) which limit or block fish migration including salmonids and smaller fish species (Rae 2005; Walsh and Long 2006). If glochidia fail to encounter a suitable host fish, the larval mussels will be unable to transform into adults and complete their life cycle. Recently (2007), at least 100 live mussels, varying in size and with heavily worn periostracum, were found between two of the weirs in the Okanagan River (south of Skaha Lake). This could imply that host fishes have been or are currently able to access this section of the river. However, recent surveys within the Okanagan River found that the periostracum of most individuals, both live and dead, was much more heavily worn than that of individuals found in other sites (Ramsay pers. obs.). This is likely the result of individuals being tumbled through dams and/or weirs and/or from sediment abrasion.

Fluctuating water flows regulated via dams alter the natural flow of the water (Rae 2005) and may be detrimental to mussels. A recent study in California, that included *G. angulata,* found that high flows can disrupt spawning and glochidial release and/or push host fish into habitats unsuitable for survival of excysting juveniles (Haley *et al.* 2007).

Flood control in the Okanagan basin affects water levels in all lakes, as well as flow delivery in the channelized and unchannelized sections of the river. Historically, Okanagan Lake levels were regulated in a staged process that may have exceeded 1 m variation over the course of a year, and may have included reductions during the vulnerable winter months potentially causing desiccation of exposed mussels that occurred in shallow water (McKee pers. comm. 2009). However, in an attempt to accommodate salmonid spawning and overwintering eggs, reductions in recent years have usually been completed prior to October and are less than 1 m, except in high snowpack years, as outlined in the current Okanagan Lake Regulation System Operating Plan (McKee pers. comm. 2009). Thus, mussel desiccation in Okanagan Lake is not likely except possibly in protected bays where the surface freezes or during very high snowpack years (McKee pers. comm. 2009). With respect to the remaining basin lakes including Skaha, Vaseux, and Osoyoos lakes, levels fluctuate more frequently but to a much lesser extent (i.e., usually 0.10–0.20 m; McKee pers. comm. 2009). Lake level regulation is unlikely to be a significant factor for mussel survival in these lakes.

In conclusion, the scouring effect associated with water release from dams and weirs to moderate flood conditions in the lakes has been and continues to be a significant threat to remaining mussel populations in Okanagan River. In terms of barriers to dispersal, it is difficult to draw any conclusions with respect to effects on host fish given that the host species remain unknown.

Development of shoreline and littoral zones

The Canadian range of *G. angulata* coincides with an area where human population is rapidly growing. Since 1940, the population of the Canadian Okanagan basin tripled every 30–40 years, reaching 300,000 in 2002 (Jensen and Epp 2002). This growth has resulted in considerable loss and alteration of the natural shoreline and littoral zones which has likely affected mussel habitat. However, no direct studies have been conducted and *G. angulata* may inhabit depths beyond the littoral zone (see **Habitat requirements**).

Major alterations to the shoreline and littoral zones throughout the range of *G. angulata* include dredging, agricultural development and modification of the natural shoreline for residential, commercial and industrial purposes. Installing docks and marinas by dredging the littoral zone can harm mussels through direct, physical disturbance or by creating large amounts of suspended material that can smother and kill mussels downstream (see **Channelization of the Okanagan River**). The construction of groynes (a structure perpendicular to shore designed to trap sediment) and breakwaters along the residential sections of shoreline in the Okanagan basin are common; these rock structures alter water flow and result in deposition of materials to create beaches (Robbins pers. comm. 2009). Removal of riparian vegetation associated with these developments can have local impacts on light and temperature conditions, altering phytoplankton and aquatic vegetation growth (Strayer 2008). Agricultural development, such as orchards, vineyards, and livestock farms come within close proximity to the shoreline; as a result, runoff such as fertilizers, herbicides and pesticides can flow into the littoral zone (see **Pollutants**). The addition of lawns and sand are often used to make waterfront properties aesthetically and physically pleasing to humans. Morris and Corkum (1996) found greater temperature fluctuations and higher ammonia and nitrogen content at grassy riverine riparian zones than at forested sites; ammonia is considered toxic to mussels (Strayer 2008). If sand that is artificially added to the shoreline washes out, the natural environment of the littoral zone changes and mussels can become buried, resulting in death (see **Channelization of the Okanagan River**). In addition, changing the substrate may result in habitat that may become inappropriate for settlement and development of juvenile mussels.

In the Okanagan region, some of the above activities (e.g., creation of beaches, dumping of sand, and removal of littoral vegetation) are considered illegal and almost all require permitting under the B.C. *Water Act*. Unfortunately, a recent compliance analysis indicated that for developed sites on both Okanagan Lake (35 sites assessed within 30 km shoreline) and Skaha Lake (194 sites assessed for entire shoreline) non-compliance was almost 100% (Robbins pers. comm. 2009). Furthermore, an estimate in the mid-1990s indicated that 80% of the lake’s southwestern and northern shoreline had already been altered in some way (Rae 2005); this is where the mussels have been reported to date. Similarly, with the 1958 channelization of the Okanagan River, 85% of the riparian vegetation was also lost (Rae 2005).

To conclude, most of these riparian and foreshore development impacts to mussels are considered localized when considered separately (i.e., direct mortality and reduced habitat quality). In considering the predictions regarding urban expansion in the water basin, as well as already impacted proportions of the basin and lack of compliance, the cumulative effects of these impacts is currently and will increasingly be one of the most significant threats to *G. angulata* in shallow littoral areas.

Pollutants

The effects of pollution have not been assessed specifically for *G. angulata*. In general, freshwater mussels are vulnerable to toxic substances at all life stages (Cope *et al.* 2008), and may be particularly sensitive to certain substances during glochidial and early juvenile stages (Wang *et al.* 2007). The three most problematic classes of pollutants for freshwater mussels include: ammonia; pollutants with high affinity for sediments; and endocrine disruptors (Strayer 2008). 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 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).

In B.C. these contaminants may originate from several sources, including land development, agricultural practices, storm water runoff, on-site sewage systems, forestry and range activities, atmospheric deposition and boating and marine activities. Even small amounts of contaminants in small amounts of runoff can result in cumulative effects, affecting the entire watershed (B.C. Ministry of Environment 1999). In the U.S., *G. angulata* has shown some tolerance of increasing nutrient loads in the middle Snake River and elsewhere (COSEWIC 2003); however, there has been no research in Canada.

The following discussion focuses on the Okanagan basin, the only river basin in Canada confirmed to contain *G. angulata*. With respect to nutrient loading, tertiary sewage treatment was implemented in the water basin in the 1980s and has effectively eliminated any concerns of nutrient loading in Okanagan Lake, considered oligotrophic. Nutrient loading associated with agricultural practices may have been a concern historically but best management practices have reduced levels significantly although elevated inputs of nitrates may still occur locally on tributaries to the lakes (Jensen pers. comm. 2009). Osoyoos Lake, however, 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 runoff 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.

Levels of copper, recently discovered to be detrimental to early mussel survival (e.g., Wang *et al.* 2007) are measured throughout the Okanagan basin (Jensen pers. comm. 2009). Results indicated that some tributaries 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). One substance group which may be a concern is pharmaceuticals (i.e., that behave as endocrine disruptors) in treated sewage particularly in localized areas downstream of the treatment plants at Okanagan Falls and in Penticton; studies to determine levels are currently underway (Jensen pers. comm. 2009).

In summary, past land-use practices may have contributed more pollutants detrimental to mussels in the watershed; however, the degree to which this occurred remains unknown. Some pollutants may still have localized impacts to aquatic communities in the Okanagan basin. Improved practices and tertiary sewage treatment over the past decade have undoubtedly improved water quality in the basin and are not thought to have significant widespread impacts to the water quality in Okanagan Lake.

Other introduced species

Additional introduced species, including fish, Eurasian Watermilfoil (*Myriophyllum spicatum*) and crustaceans are also believed to be threats to *G. angulata* in Canada.

Non-native fish may affect mussels through predation at any life history stage (except possibly larger adults), through displacement or competition for resources with native host fish, or through habitat alteration. The introduced Pumpkinseed Sunfish (*Lepomis gibbosus*) is a specialized molluscivore and is likely to affect recruitment (Strayer 1999); similarly many carp species are known to eat molluscs in addition to being significant bioturbators.

If glochidia attach to a non-host fish (e.g., an introduced species), a cyst may not fully develop, resulting in glochidial death (Rogers-Lowery and Dimock 2006; O'Brien pers. comm. 2008). In addition, loss of host fish has been known to cause a decline of mussels (see **Channelization of the Okanagan River**). In B.C., there are likely 12 introduced fish species in water bodies where *G. angulata* has been found. For example, Smallmouth Bass have been reported from Vaseux and Osoyoos Lakes for over 100 years (suspected from stocking in the U.S.; Mitchell pers. comm. 2008), but this fish is also a host for many mussels in southern Ontario. Common Carp are notorious for degrading littoral areas (e.g., uprooting aquatic macrophytes) and are prevalent throughout the Okanagan basin (Mitchell pers. comm. 2009). However, these fish have been present for decades and it is not clear if the habitats they affect are those preferred by *G. angulata*. Until host fishes for *G. angulata* are identified, direct or indirect impacts of introduced fish are unknown. Additionally, it is possible that introduced fish species could become host fish, as evidence suggests that *G. angulata* are host generalists.

Eurasian Watermilfoil, *Myriophyllum spicatum,* is an introduced aquatic plant that has become established in all the main lakes in the Okanagan (Okanagan Basin Water Board 2008). The plant can displace virtually all other aquatic macrophytes and may interfere with fish spawning (Canadian Wildlife Service 2008). Two mechanical eradication methods are currently used in the Okanagan basin (Okanagan Basin Water Board 2008), one of which poses a considerable threat to *G. angulata*. Rototilling (also called “de-rooting”) occurs in the winter; the rototiller blades penetrate and turn 12–23 cm into the substrate to remove roots at depths of 4.5 m or less. This is in similar substrate and depths to where mussels are found. Because rototilling occurs at and near known sites of live *G. angulata* (Dunbar 2009; British Columbia Conservation Data Centre 2008), it is likely a significant threat, as it can potentially cause harm or mortality from the direct impact of the blades and/or burial from the sedimentation that results from the de-rooting process (L. Gelling unpublished). Impacts of rototilling, however, have not been formally tested, but in 2007, one person snorkelled in an area where rototilling had occurred and in an adjacent area where it had not occurred. No mussels were observed in the area that had been rototilled; however, mussels were found in abundance within the non-rototilled area (Sarell pers. comm. 2007). The second eradication method is harvesting. In summer plants are mowed about 2 m below the surface of the water; this method is likely not a significant threat to *G. angulata*.

The Asiatic Clam, *Corbicula fluminea*, is another introduced mollusc species within North America that poses a threat to native mussels (Mackie and Claudi 2010). Indeed, one of the earliest records of *Corbicula fluminea* is from Vancouver Island in 1924 (Mackie and Claudi 2010). These clams reach high densities, affecting the survival and growth of newly metamorphosed juvenile freshwater mussels (Yeager *et al.* 2000). This species can survive in almost any freshwater environment except ephemeral streams and the lake hypolimnia and has been correlated with sand/silt/organic substrate (Strayer 1999; NatureServe 2008), similar to the substrate where *G. angulata* has been found in Canada. In British Columbia, *Corbicula fluminea* has been recently recorded on southern Vancouver Island and near Vancouver (Frederick pers. comm. 2008; Kirkendale and Clare 2008). The closest occurrence to *G. angulata* is Coquitlam, approximately 350 km west of Osoyoos Lake. The dispersal method within North America is unknown (USGS 2008).

Finally, *Mysis relicta* is a small freshwater shrimp that was introduced to Okanagan Lake in 1966 as an additional food source for Kokanee. Subsequently they have been found to compete with the salmon and other fish for food and have been directly linked to a decline in Kokanee production. They have since been found throughout the Okanagan basin, south to Osoyoos Lake, although not as numerous in the other lakes (Rae 2005). It is unknown how the decline in fish and the change in the nutrient levels in the lakes may affect *G. angulata.*

SPECIAL SIGNIFICANCE OF THE SPECIES

This species is the only known living taxon in its genus, although fossil congeners have been documented (Taylor 1988; Watters 2001) dating at least to the Miocene, five million years or more ago (e.g., *Gonidea coalingensis* [Taylor 1985]). *Gonidea* has occurred essentially in its present range since the Late Cenozoic (Neogene). The genus is taxonomically isolated and not closely related to any of the numerous eastern North American mussels (Lydeard *et al.* 1996; Watters 2001). There may be one additional living species from Korea (Taylor 1988), providing one of the most significant examples of the Asian affinities of the western North American freshwater mollusc fauna. *Gonidea angulata* is one of only a few unionids in western North America.

In Canada the ecological role of *G. angulata* is unknown, but freshwater mussels in general are important contributors to aquatic ecosystems and can be used as indicators of freshwater ecosystem health (Bertram and Stadler-Salt 1999; Grabarkiewicz and Davis 2008). Burrowing bivalves in freshwater ecosystems filter phytoplankton, bacteria and particulate organic matter from the water column, affect nutrient dynamics, increase sediment water and oxygen content, release nutrients from the sediment into the water column, stabilize sediment and create habitat and refugia for other organisms (Vaughn and Hakenkamp 2001). Waste products can alter the composition of benthic communities, enhancing local algae and macroinvertebrate populations (Vaughn *et al.* 2007; Vaughn and Spooner 2006, as cited in Strayer 2008). Freshwater mussels are also an integral component of food webs, consuming detritus, organic matter and a wide range of organisms (e.g., diatoms, phytoplankton, and bacteria) from the water column (Strayer 2008). Conversely, freshwater mussels may be consumed by both aquatic and terrestrial predators (see **Predation**).

First Nations' use of this species has been documented from the Interior Columbia basin. Freshwater mussel shell middens have been located in British Columbia, Montana, Idaho, Nevada, Oregon, Washington, and California (Lyman 1980). The Flathead First Nations of Montana and the Umatilla First Nations in Oregon have used freshwater mussels such as *G. angulata*, *Margaritifera falcata*, and *Anodonta* spp. for food, tools, and ornamentation (COSEWIC 2003), as have the Karuk people of northern California (Norgaard 2004).

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

Gonidea angulata is ranked globally as G3, nationally in Canada as N1, and nationally in the U.S. as N3 (NatureServe 2008). In the province of British Columbia, it is listed as S1 (British Columbia Conservation Data Centre 2008). In the U.S., it is listed as S1S2 in California, S2/S3 in Oregon, S2 in Washington, and is not ranked (SNR) in Idaho and Nevada (NatureServe 2008). *Gonidea angulata* is not listed under the United States *Endangered Species Act,* the International Union for Conservation of Nature (IUCN) Red List, or the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

There are no restrictions on the recreational collection of unionids in B.C., except that they may be collected by hand only (Gauvin pers. comm. 2009). However, according to the federal *Fisheries Act* and the provincial *Wildlife Act,* possessing, transporting, trafficking, releasing and transferring live animals are illegal without a permit or authorization (Department of Justice Canada 2008a; B.C. Ministry of Environment 2008f). According to the 2008/09 B.C. freshwater fishing regulations, it is unlawful to use invertebrates as bait for fishing on lakes (B.C. Ministry of Environment 2008g), but aquatic invertebrates may be used as bait in a stream, unless there is a bait ban (Gauvin pers. comm. 2009). The *Fisheries Act* contains provisions that can be applied to regulate flow needs for fish, fish passage, killing of fish by means other than fishing, the pollution of fish-bearing waters, and harm to fish habitat (see **HABITAT**, **Habitat protection/ownership**).

Because this species is currently a species of Special Concern (Schedule 1) under the Canadian *Species at Risk Act* (Species at Risk Public Registry 2010), a management plan for the species and its habitat must be implemented, including measures for the conservation of the species (Species at Risk Public Registry 2008). This plan is currently in progress as of February 2009 (Heron pers. comm. 2009).

Gonidea angulata occurs within the boundary of Vaseux Lake Provincial Park. The park encompasses approximately 8 km^2 of the littoral zone, where live specimens have been located. A licence is required to collect mussels from inside provincial parks.

Under regional and municipal bylaws, the *Community Charter Act* and *Municipal Act* allow local governments additional powers to protect fish (molluscs are included under the definition of fish) and habitat (B.C. Ministry of Community Development 2008a,b) (see **HABITAT**, **Habitat protection/ownership**).

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AUTHORITIES CONTACTED

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Dyer, O. Wildlife Biologist, British Columbia Ministry of Environment, Penticton, British Columbia.

Fraser, D. Species Specialist. Ministry of Environment. Victoria, B.C.

Gagnon, J. Chief Collection Manager, Invertebrate Section. Canadian Museum of Nature. Ottawa, Ontario.

Goulet, G. Science Project Officer, ATK. Environment Canada Species Assessment. Gatineau, Quebec.

Haley, L. Spring Rivers Ecological Sciences, LLC Cassel, California.

Heron, J. Invertebrates at Risk specialist. Ministry of Environment, Vancouver, B.C.

Mitchell, J. Resource Inventory Specialist, British Columbia Ministry of Environment. Penticton, B.C.

Nantel, P. Species Assessment Specialist. Ecological Integrity Branch, Parks Canada. Gatineau, Quebec.

O'Brien, C. Browns River Environmental Consultants. Underhill, Vermont.

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BIOGRAPHICAL SUMMARY OF REPORT WRITERS

Lea Gelling is a zoologist with the British Columbia Conservation Data Centre (CDC) in Victoria, B.C., specializing in ranking freshwater and terrestrial molluscs of the province and mapping red and blue-listed invertebrates and vertebrates. Ms. Gelling graduated with a B.Sc. (with distinction) as part of the biology co-op program from the University of Victoria in 2004. As a student, she worked at the Vancouver Aquarium where she studied gut content of wild, B.C. saltwater fish, the Royal British Columbia Museum, where she worked with the northern dragonfly collection and the CDC, where she compiled data and information on B.C.'s freshwater and terrestrial molluscs and initiated the first Conservation Status Ranks for this group. Ms. Gelling has been interested in freshwater mussels since she was a child, having spent countless hours on Okanagan Lake attempting to collect as many mussels as she could in one breath.

Leah Ramsay is the senior zoologist with the British Columbia Conservation Data Centre (CDC) in Victoria, B.C. where she has worked for the past 15 years. In this role she coordinates and does the species assessments and assigns the Conservation Status Ranks for the provincial fauna, both vertebrates and invertebrates. She has also worked with NatureServe (member of IUCN) to establish the assessment methodology that is used across the network. Leah has participated in a number of surveys for mussels and worked on the resulting mapping and provincial assessments. Birds and dragonflies are her other specialities.

Susan Pollard received her M.Sc. from the University of Guelph in 1992 specializing in salmonid population genetics. She has worked for the Province of British Columbia for 12 years, first in the role of Fish Geneticist and, more recently, as the Aquatic Species at Risk Specialist. Both roles have required a solid foundation in conservation biology particularly as they apply to freshwater fisheries management. Susan is responsible for coordinating freshwater fish priorities for federal/provincial SAR planning purposes (including research and information needs, recovery activities and management planning), as well as ensuring the status of fish under provincial jurisdiction is correctly represented by the B.C. Conservation Data Centre. Susan has been a jurisdictional member of COSEWIC since 2006.

COLLECTIONS EXAMINED

Museums that hold Canadian records of *G. angulata*:

Canadian Museum of Nature, Ottawa, Ontario

Royal British Columbia Museum, Victoria, British Columbia

University of Michigan Museum of Zoology, Ann Arbor, Michigan

Smithsonian National Museum of Natural History, Washington, D.C.