COSEWIC
Assessment and Status Report

on the

Rocky Mountain Ridged Mussel
Gonidea angulata

in Canada

SPECIAL CONCERN
2003

COSEWIC
COMMITTEE ON THE STATUS OF
ENDANGERED WILDLIFE
IN CANADA

COSEPAC
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DES ESPÈCES EN PÉRIL
AU CANADA

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For additional copies contact:

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

Tel.: (819) 997-4991 / (819) 953-3215
Fax: (819) 994-3684
E-mail: COSEWIC/COSEPAC@ec.gc.ca
http://www.cosewic.gc.ca

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Cover illustration:
Rocky mountain ridged mussel — Drawing of *Gonidea anuglata* (from Burch 1975).

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COSEWIC
Assessment Summary

Assessment Summary – November 2003

Common name
Rocky Mountain Ridged Mussel

Scientific name
Gonidea angulata

Status
Special Concern

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

Occurrence
British Columbia

Status history
Designated Special Concern in November 2003. Assessment based on a new status report.

COSEWIC
Executive Summary

Rocky Mountain Ridged Mussel
Gonidea angulata

Species information

The freshwater mussel *Gonidea angulata,* commonly known as the Rocky Mountain Ridged Mussel, was described by Lea in 1839. The shell is 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 to the angular basal posterior margin of each valve. Juveniles of this species may be greenish/tan in appearance while adults are typically darker, becoming bluish-black.

Distribution

The Rocky Mountain Ridged Mussel occurs from southern British Columbia in the Columbia River system south in Washington, Oregon, Idaho, Nevada and south-central California. Recently (April 2002), a dead shell of *Gonidea angulata* was collected from Park Rill Creek, a tributary to the Okanagan River, in the vicinity of Oliver, B.C. Other recent collections (1991) of live specimens in B.C. are from Skaha Lake and Vaseux Lake. Other collections have been made from Osoyoos Lake, Okanagan Lake at Okanagan Falls, and from Okanagan Lake (Haynes Point Park). Collections from these locales have occurred between 1906 and 1991. It is not known if the shells were collected live or dead. Historically, this species occurred from southern British Columbia to south-central California; however, the current range is believed to be considerably smaller.

Habitat

Habitat occupied by *G. angulata* is generally characterized as substrates of lakes, streams, and rivers that range in size from gravel to firm mud with the presence of at least some fine material (e.g. sand, silt or clay). Preferred sites generally have constant flow, rather shallow water (typically < 3 m in depth), and well-oxygenated substrates, especially when occurring in finer sediments.

Biology

There is relatively little specific information available regarding the biology of *G. angulata*. At present it is presumed to reproduce like other unionids, via internal

fertilization, producing glochidia that are parasitic (commesalistic) on an undetermined fish host. Due in part to its broad historical range, glochidia of *G. angulata* are likely associated with more than one species of fish. Adults of this species are generally sessile and may move only if repeatedly disrupted. From counts of annual growth rings, it is believed that *G. angulata* can live up to about 30 years.

Population sizes and trends

Population sizes in British Columbia have not been determined; however, they are believed to be declining, which may be inferred from the relatively few specimens of *G. angulata* collected and preserved in Canadian collections and declines in habitat water quality. There appear to be two distinct, severely fragmented populations of *G. angulata* in the Okanagan River system. In the U.S., this species is patchily distributed and locally abundant. In general, U.S. populations of *G. angulata* are regarded as declining. Documented densities in some areas are as high 183/m^2 and local populations can be in the tens of thousands.

Limiting factors and threats

In both British Columbia and the western United States this species is threatened by the continued loss or degradation of suitable habitat. In general, unionid mussels are very sensitive to environmental changes and consequently the order contains a high percentage of endangered species in North America. Other threats to this species are eutrophication, heavy metals, and transition elements. In the short-term, a proposed re-alignment of the Okanagan River could negatively impact existing *G. angulata* populations, which would presumably benefit over the long-term.

Special significance of the species

This species is the only known living taxon in the genus. The monospecific *Gonidea*, however, has an extensive fossil record in the western portions of the U.S., dating at least to the Miocene. The genus is taxonomically isolated and not closely related to any of the numerous eastern North American forms. There may be one additional living species from Korea, thus providing one of the most significant examples of the Asian affinities of the western North American freshwater mollusc fauna.

Existing protection

No explicit protection exists for this species. Globally this species is considered to be vulnerable. In B.C., the exact status of *G. angulata* is unknown; however, some currently believe the species to be at least threatened. *Gonidea angulata* occurs on British Columbia's Red-list, which includes any indigenous species or subspecies that have, or are candidates for, Extirpated, Endangered, or Threatened status in British Columbia.

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 5th 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 organizations (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biosystematic Partnership, chaired by the Canadian Museum of Nature), three nonjurisdictional members and the co-chairs of the species specialist and the Aboriginal Traditional Knowledge subcommittees. The committee meets to consider status reports on candidate species.

DEFINITIONS (AFTER MAY 2003)

Species	Any indigenous species, subspecies, variety, or geographically or genetically distinct population of wild fauna and flora.
Extinct (X)	A species that no longer exists.
Extirpated (XT)	A species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A species facing imminent extirpation or extinction.
Threatened (T)	A species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A species of special concern because of characteristics that make it particularly sensitive to human activities or natural events.
Not at Risk (NAR)**	A species that has been evaluated and found to be not at risk.
Data Deficient (DD)***	A species for which there is insufficient scientific information to support status designation.

* 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.

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SPECIES INFORMATION

Name and classification

Species Name	*Gonidea angulata* (Lea, 1839) according to Clarke (1981): 1838 according to Taylor (1981) and Turgeon *et al.* (1998).
Kingdom	Animalia
Phylum	Mollusca
Class	Bivalvia
Order	Unionoida
Family	Unionidae (Pearly Mussels) (higher classification from Turgeon *et al.*, 1998)
Subfamily	Ambleminae according to Clarke (1981): Gonideinae according to Heard and Gluckert (1971) and Davis *et al.* (1978): tribe Gonideini according to Davis and Fuller (1981). Lydeard *et al.* (1996) consider the genus *Gonidea* as not closely related to any other North American forms. See discussion of ancestry and relationships below.
Genus	*Gonidea*
Species	*angulata*
Common Names	
COSEWIC name:	Rocky Mountain Ridged Mussel
Other:	• Western Ridged Mussel • Western Ridgemussel • Rocky Mountain Ridged Mussel • American Fisheries Society common name: western ridged mussel (Turgeon *et al.*, 1998).

Synonyms	• *Anodon feminalis* Gould,1850;
	• *Anodonta randalli* Trask, 1855;
	• *Anodon biangulata* Sowerby, 1869;
	• *Anodonta angulata* var. *subangulata* Hemphill, 1891*;*
	• *Gonidea angulata* var*. haroldiana* Dall, 1908 (Taylor, 1977).
	• Invalid usages include:
	  • *Margarita* (*Anodonta*) *angulata* Lea, 1838; *Anodonta feminalis* Gould, 1852;
	  • *Margaron* (*Anodonta*) *angulata* Lea, 1870;
	  • *Anodonta biangulata* Clessin, 1876 (Henderson, 1929).

Type Locality:	Taylor (1981) indicates that “Lewis’s River”, now interpreted as the Snake River, Idaho (with no specific locality), as the type locality for *Gonidea angulata*.

Museum Collections

Collections of *G. angulata* exist in the following museums:

- Canadian Museum of Nature, Ottawa, Ontario, Canada
- Royal British Columbia Museum, Victoria, British Columbia, Canada
- Field Museum of Natural History, Chicago, Illinois USA
- California Academy of Sciences, San Francisco, California USA
- National Museum of Natural History, Washington, USA
- Colorado University Museum, Boulder, Colorado, USA
- University of Michigan Museum of Zoology, Ann Arbor, Michigan, USA
- Academy of Natural Sciences of Philadelphia, Philadelphia, Pennsylvania, USA
- Ohio State Museum of Zoology, Ohio State University, Cincinnati, Ohio, USA
- Museum of Comparative Zoology, Harvard University Cambridge, Massachusetts, USA
- American Museum of Natural History, New York, New York, USA

Several smaller institutions have been reviewed for lots of this species by Frest (1985-1997).

Museums that contain Canadian records include:

- Canadian Museum of Nature, Ottawa, Ontario, Canada
- Royal British Columbia Museum, Victoria, British Columbia, Canada
- University of Michigan Museum of Zoology, Ann Arbor, Michigan, USA

Classification

The taxonomy and relationships of this form are somewhat problematic at present, despite considerable study. Many authors, including Ortmann (1910, 1916), have regarded *Gonidea* as exceptionally distinctive, belonging to its own subfamily or family, ranked closest to the Amblemidae or Ambleminae among North American Unionoida (e.g., Heard and Gluckert 1971; Davis *et al*. 1978; Davis and Fuller 1981). Some authors, such as Heard (1974) and Taylor (1985, 1988), stress that it has possible Asian affinities. The first, rather preliminary, rRNA study of unionoideans placed *Gonidea* close to *Ambleminae* (Rosenberg *et al*., 1994). The more complete study by Lydeard *et al*. (1996) concluded that Gonidea is not closely related to any other North American Unionacea. Nagel *et al*. (1998) suggest relationship of the problematic European form *Potamida* littoralis to the Gonideini, based primarily on anatomical features. Unless Taylor (1988) is correct about the Korean unionid of Yoo and Habe (1962), there is only one extant taxon (without subspecies) and four fossil taxa (Watters, 2001). The most recent study, by Graf (2002), confirms the placement of *Gonidea* in the Ambleminae and recognizes that subfamily as endemic to North America.

Description

Gonidea angulata is a large freshwater mussel that exhibits features typical of its subfamily Ambleminae (Elliptioninae). The subfamily Ambleminae is characterized by heavy hinge teeth; however, *G. angulata* has a moderately heavy hinge but rather indistinct hinge teeth. The Ableminae is also characterized by all four demibranchs being marsupial, by hookless glochidia, and by a short breeding season (tachytictic).

Clarke (1981) provides the following description for *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 to the angular basal posterior margin of each valve (Figure 1). 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 8 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.”

Frest and Johannes (in press) add: “See Burch (1973, 1975) for best short description and illustration (1973, figure 11). This taxon is very distinctive. *Gonidea angulata* has a moderately heavy hinge but rather indistinct hinge teeth; has a sharp posterior ridge; the posterior length exceeds the anterior, but the shell is not winged; shell periostracum generally greenish, sometimes lightly rayed with yellow; shell generally thin; nacre coppery blue-white; length 7-more than 9 cm.” (Figure 2).

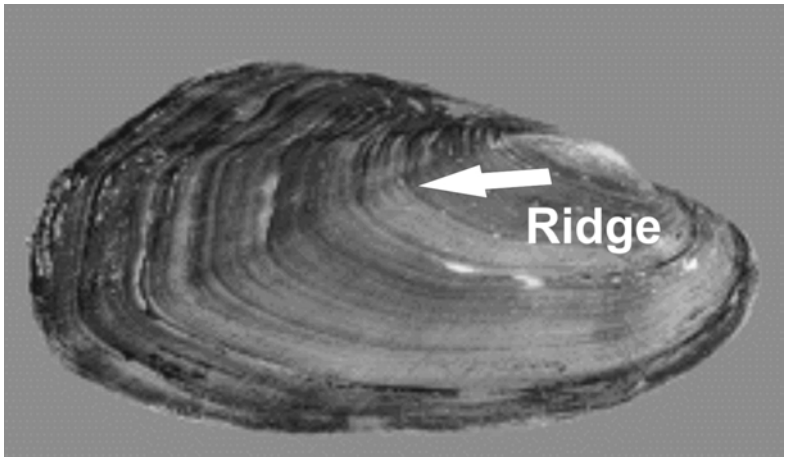

Figure 1. Image of *Gonidea angulata* showing the angular ridge typical of this species.

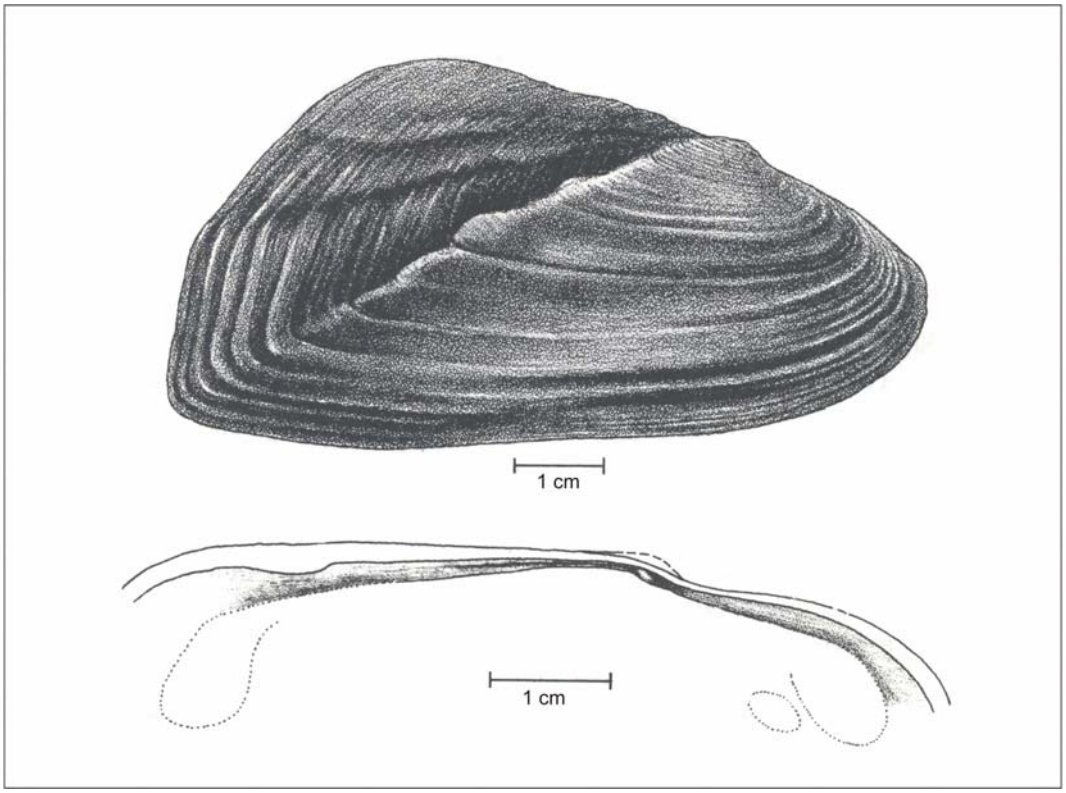

Figure 2. Drawing of *Gonidea angulata* (from Burch 1975).

For another illustration, see McMahon and Bogan (2001, fig. 28U).

DISTRIBUTION

Global range

The range of *G. angulata* is described as “Southern British Columbia to southern California, eastward to southern Idaho and northern Nevada” (Taylor 1981). Burch (1975) described the range as central California, north to British Columbia and east to Nevada and Idaho. Currently, *G. angulata* is known from portions of western North America only, mostly south of the Wisconsinan glacial margin. West of the Cascades, *G. angulata* is seemingly absent from the Olympic Mountains, Washington and points north, but occurs sporadically in the Willapa Hills (southwest Washington) and northwest Oregon, and occurs more continuously from southwest Oregon south to southern California. East of the Cascades, *G. angulata* occurs in the interior of Washington and Oregon, in southern Idaho and in northern Nevada.

Taylor (1981) described its distribution in California as “formerly throughout most of the State, in the following drainages: Lower Klamath, upper Klamath River and Lost River; Pit River; Central Valley; north coast streams (lower Eel River and lower Russian River); Clear Lake (including Blue Lakes); Pajaro-Salinas system (Pajaro River only); Los Angeles Basin (Ballona Creek and Santa Ana River). Probably extinct in most of the Central Valley and southern California.” This suggests both a somewhat patchy original distribution and a considerable recent reduction in historic range.

Henderson (1929, 1934, 1936 a,b) provides information on some interesting sites, including claims for distribution in Utah and Montana. One of the authors (TJF) was unable to confirm Utah and Montana sites from museum records. Chamberlin and Jones (1929) do not list this taxon from Utah.

Canadian range

Gonidea angulata has been found in the Columbia River system in southern British Columbia (Okanagan and possibly the Kootenay) (Clarke 1981) and is known in Canada only from the main, valley-bottom water bodies from Penticton south to the border and the only recent museum records (1991) are from the following areas:

Okanagan River at Okanagan Falls,
Vaseux Lake,
Skaha Lake,
and Osoyoos Lake.

Given the current distribution of *G. angulata* in the Columbia River and associated tributaries in northeastern Washington, it is probable that *G. angulata* is present in some equivalent portions of southern British Columbia (i.e., in areas not currently documented as occupied or known breeding areas).

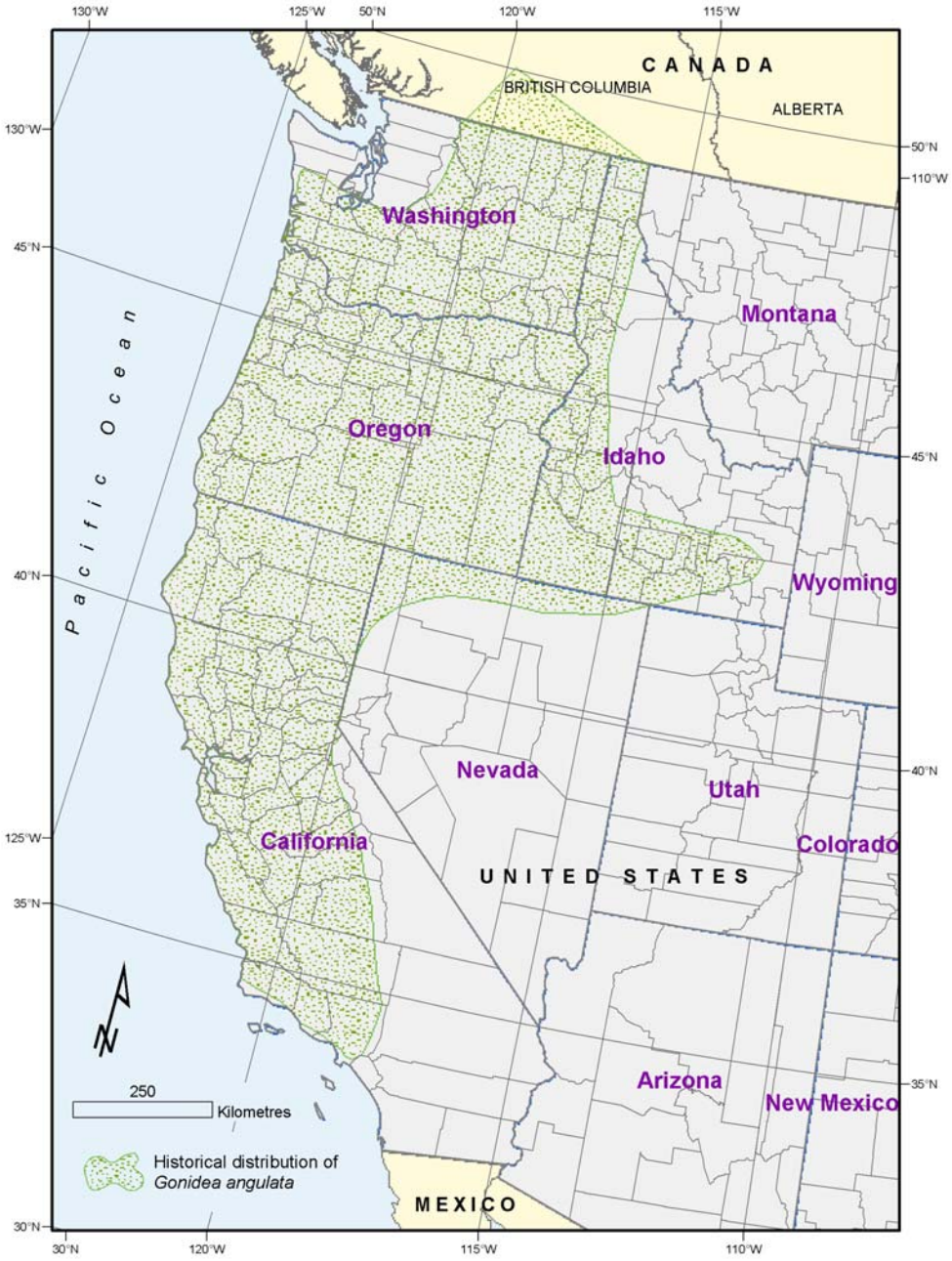

Figure 3. Historical range of *G. angulata* in British Columbia and the Pacific Northwestern United States.

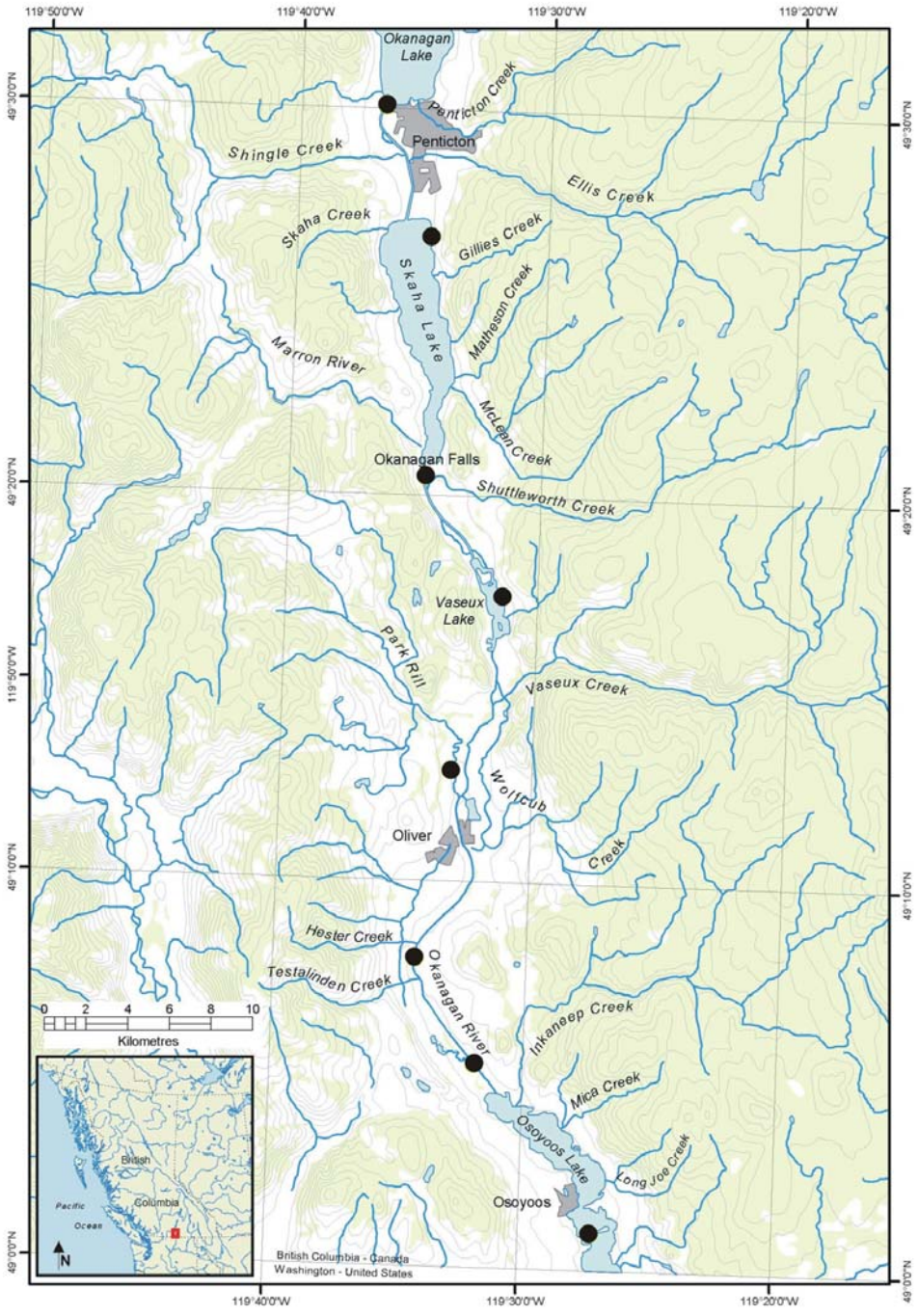

Figure 4. The distribution of *Gonidea angulata* in British Columbia. Black dots represent the approximate location of known sites (from museum records and/or recent collections). Named tributaries of the Okanagan River represent the potential range for this species.

Table 1 identifies some recent records of *G. angulata* in B.C. (from Taylor (1993) and from museum records). However, addition of new sites would not likely increase the extent of occurrence (209 km^2) significantly. The actual area of occupancy is estimated at 31.5 km^2, but is much less than 100 km^2.

Table 1. Records of *G. angulata* from the Canadian Museum of Nature and Royal British Columbia Museum.

Catalogue No.*	Collector	Collection Date	Location and Site Description	No.of Specimens
CMNML 093118	G.E. Winkler	March 1906	Okanagan River where it leaves Okanagan Lake	2+
CMNML 009683	R.J. Drake	20 August 1960	Okanagan Falls	-
CMNML 016017	R.J. Drake	19 August 1960	Okanagan Falls	1
	D. W. Taylor	12 June 1963	Okanagan River, Okanagan Falls Park,	
CMNML 067553	A.H. Clarke, B.T. Kidd	06 August 1972	Vaseux Lake 13.6 km N of Oliver at public beach	4
CMNML 086690	T. Tuominen, S. Yee	10 April 1982	Oliver, B.C.. Okanagan R. Half way between Oliver and Osoyoos Lake entrance	1
CMNML 086692	T. Tuominen, S. Yee	28 April 1982	Osoyoos Lake. Okanagan R. ± 1.5 km upstream (N) from entrance Osoyoos Lake	1
CMNML 086693	T. Tuominen, S. Yee	4 April 1983	Osoyoos Lake. Okanagan R. ± 1.5 km upstream (N) from entrance Osoyoos Lake	3
RBCM	D. W. Taylor	16 August 1990	Osoyoos Lake, N. side of Haynes Point Provincial Park,	2
RBCM	D.W. Taylor	09 August 1991	Skaha Lake, Penticton. 1.12 km south of intersection of Brantford avenue and Lakeside Road.	2

*Canadian Museum of Nature records only

To determine if *G. angulata* persists within its historical (and only known) range in British Columbia, several organizations were contacted to discuss whether or not individuals in the area had seen this species. In particular, the Osoyoos Lake Water Quality Society was contacted and the potential presence of this mussel was discussed. Subsequently, all members of the Osoyoos Lake Water Quality Society were alerted to the potential presence of *G. angulata*, and as a society initiated informal searches for this species (i.e., individuals or small groups would include visual searches for shells or live mussels as part of their activities during walks). Searches were conducted along the Okanagan River and its tributaries, and around the shores of Osoyoos Lake. As of 2 August 2002, 1 specimen has been positively identified as *G. angulata* and this

specimen consists of half of a shell (Figure 5). The specimen was collected from Park Rill Creek within the town limits of Oliver, B.C.. Unsubstantiated information suggests that there are live specimens within Park Rill creek and other nearby tributaries of the Okanagan River near the area where the shell was collected (L. Dallas, pers. comm). To determine if the named tributaries in Figure 4 represent suitable habitat or house extant populations of *G. angulata*, extensive surveys and research to determine population sizes in each watershed would be required.

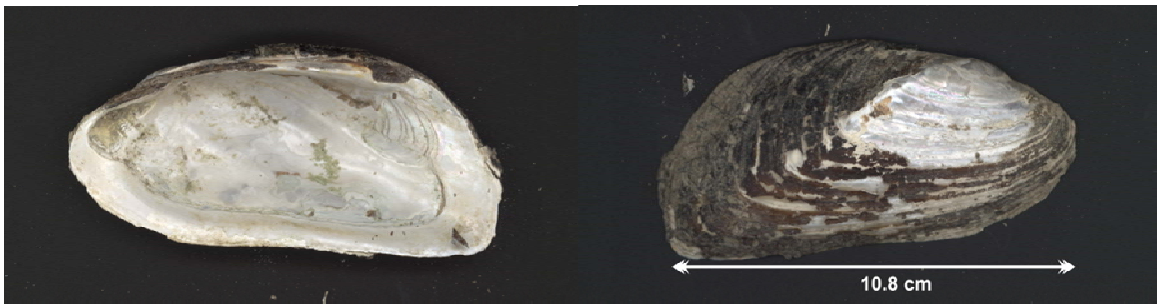

Figure 5. Scanned images of the *G. angulata* shell collected from Park Rill Creek, British Columbia, 23 April 2002. Photo V.C. Hawkes, collector: L. Dallas.

Total documented Canadian locations are 8 with only 1 of these confirmed as extant (Park Rill Creek). It is not known if this species has disappeared from historical sites.

For other recent records of *G. angulata* from the western United States, see Taylor (1981), Neitzel and Frest (1993); Frest and Johannes (1991, 1992, 1993, 1994, 1995a, 1998, 2000).

HABITAT

Habitat requirements

Gonidea angulata lives in freshwater habitats (lakes, streams, creeks, rivers) and in a variety of substrates ranging from gravel to firm mud. Presence of at least some fine material (e.g. sand, silt or clay) seems to be required, although very young specimens were noted in 1991 from coarse plant detritus at the mouth of the Okanagan River (= Okanogan in the U.S.). Sites preferred by this amniphilic (“stream/river loving”) species generally have constant flow, rather shallow water (typically < 3 m in depth), and well-oxygenated substrate, especially when occurring in finer substrates. Most known sites seem to lack macrophyte beds, although nearby stones may have a dense periphyton community. Mussels are typically found partly buried in finer substrates, often to at least half their length, and with the posterior end directed upstream. In coarser substrates, such as some Okanogan sites, mussels may be almost completely buried, with only the posterior end protruding slightly from the substrate. Generally, specimens of all non-larval age classes are found together in the same habitat.

However, in exceptional cases, as near the mouth of the Okanogan River, only juveniles are found. In this area, larger mussels are likely to suffocate, so the dominance of juveniles at a particular site should be regarded as quite atypical. In many sites where *G. angulata* was recently collected (Table 2), only large adults were found.

In Vaseux Lake near Oliver, British Columbia, large specimens occur in muddy sand at a depth of 0.6 – 0.9 m along the shoreward edge of *Potamogeton* (pond weed beds). Elsewhere, *G. angulata* has been collected in streams ranging in size from large creeks (e.g., Toppenish Creek, a tributary of the Yakima River, Washington) to large rivers (e.g., lower Columbia River, Washington / Oregon). Most specimens collected have occurred at depths ranging from 0.2 – 3 m; but some specimens have been dredged alive from the Little Granite Reservoir (Washington) from depths of approximately 10 m and from the lower Columbia River (Oregon / Washington), from depths of approximately 20 m. This species is occasionally found in impoundments in which there is some continual flow. For example, *G. angulata* occurs in some river-lake systems such as Osoyoos Lake British Columbia (Taylor 1993) and the Little Granite Reservoir and lower Snake River, Washington (Frest and Johannes, 1992; this population is now believed extinct). Populations occurring in these systems appear to be sparse, consisting only of widely scattered adults, and rarely show well-rounded demographics. The species seems to avoid nutrient-rich waters, although some populations in the middle Snake River, Idaho, have been able to withstand considerable nutrient enhancement locally. However, some streams in the historic range may have originally lacked this taxon. Current distribution in southwest Washington and northwest Oregon is very sporadic despite persistence of seemingly good habitat. Regionally, the species appears to be quite uncommon, even if locally abundant.

Gonidea angulata prefers 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. At some 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., the White Salmon River, Washington; the 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).

In British Columbia, the Okanagan River has been significantly modified from a meandering river to a canal-like waterway with in-river flood control devices. These modifications have greatly reduced salmonid runs in the river and have altered bottom sediments. These in-river modifications have likely altered suitable *G. angulata* habitat and the greatly reduced salmonid (suspected hosts) runs may have interfered with glochidial dispersal. Given the reduced salmonid population in the Okanagan River and the instream barriers that exist, it is likely that upstream dispersal is severely hampered or impossible while downstream dispersal likely occurs as a result of the movement of fish downstream. In the U.S. and Canada, the Okanagan River is dammed creating a physical barrier to fish passage and effectively reducing upstream dispersal from U.S. to Canadian populations through glochidial movement via a fish host.

Trends

In British Columbia it is thought that *G. angulata* is restricted to very specific habitats in the southern Okanagan south of Penticton; however, wide-ranging searches for this species have not been conducted. Due to the limited amount of information available on its actual distribution and occurrence it is not possible to comment directly on the population status of this species; however, due to threats to its habitat, there is reason to suspect that *G. angulata* is habitat limited and declining. For example, *G. angulata* has a requirement for cold clear, oligotrophic waters (G. Mackie, pers. comm.) and only approximately 10-20% of southern B.C. has lakes and/or streams that fit these requirements (M. Gaboury, pers. comm.). As such, it is unlikely that that this species can/will increase its current range due to the limited availability of suitable habitat.

Within its historic range, *G. angulata* is presently scattered in distribution and must be 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 (T.J. Frest, pers. obs.). 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). Frest (pers. obs.) has noted, in the Okanogan River in Washington and elsewhere, many populations in which recent recruitment seems 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 the state of Idaho.

Protection/ownership

Land ownership in the vicinity of known *G. angulata* sites in southern British Columbia varies from private to provincial, with the most recently encountered site on Park Rill Creek occurring on public property; however, only a dead specimen was found. In the U.S., areas occupied by *G. angulata* are on public land administered by the federal government (U.S. Department of the Interior, Bureau of Land Management or U.S. Department of Agriculture Forest Service).

BIOLOGY

General

Compared with some other North American freshwater mussels, relatively little is known about the biology of this taxon. This may be in part due to its rather isolated taxonomic position. Taylor (1988), for example, thought it a likely relative of the Korean genus described in Yoo and Habe (1962). Rosenberg *et al.* (1994) and Lydeard *et al.*

(1996) have also emphasized its unique taxonomic position in North America. The species has not been artificially cultivated in the laboratory or raised for more than a short period of its life span.

Life cycle and reproduction

Freshwater mussels have a complex life cycle, which includes a short parasitic stage attached to a fish host. The life of a freshwater mussel can be partitioned into five distinct stages:

a larva (called glochidium) developing in the gill of a female mussel,
a short planktonic glochidial stage expelled from the female mussel,
a brief (2-3 weeks) to long (2-4 months) parasitic (commensalistic) glochidium attached to the gills or fins of a living host fish,
a free-living benthic juvenile, and
the benthic adult mussel.

Generally, reproduction occurs when the male releases sperm into the water column, which is siphoned into the female to fertilize the eggs (Figure 6). Reproduction may be triggered by increasing water temperatures and day length. Development and retention of larvae (0.1 – 0.4 mm in size) within the female may last from 1 to 4 months (i.e. tachytictic females) to 6-10 months (i.e. bradytictic females).

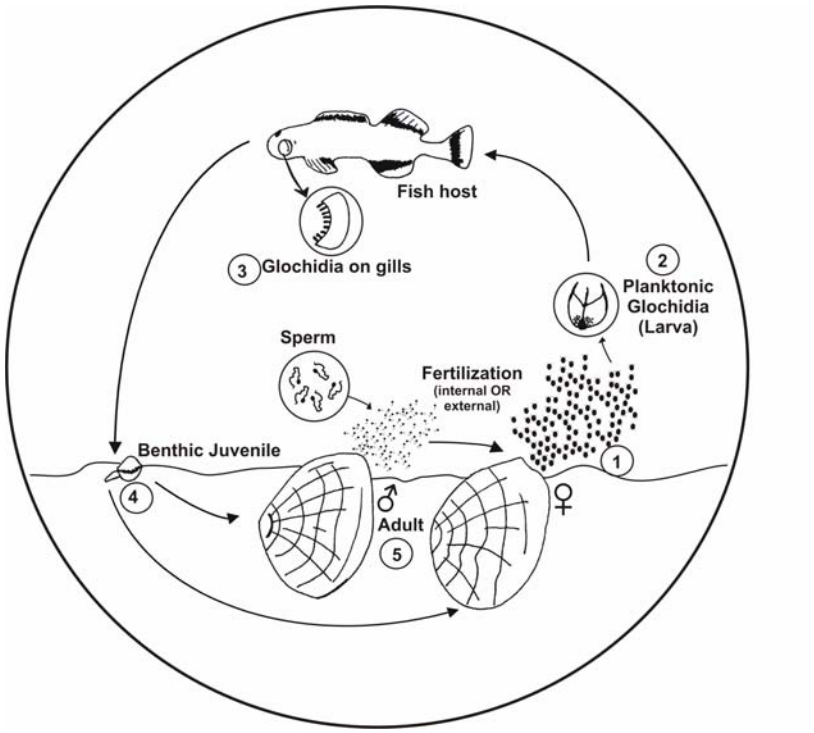

Figure 6. Generalized life cycle of a freshwater mussel. Numbers refer to the five life stages listed above.

Timing for reproduction, gravidity, egg and sperm release, and larval development are not specifically known for *G. angulata*. Collections have been made of gravid individuals in April through July but not in August through October, implying a tachytictic habit. Glochidial morphology of this species is unknown. Fertilization in *G. angulata* has not been described; however, it is likely that fertilization of the eggs is internal, as described above, as female unionids receive sperm during the process of filter feeding, at which time glochidia that are being brooded in the marsupial compartment of the gills are fertilized. It is unlikely that female *G. angulata* eject their larva in bound mucilaginous tubes called conglutinates. If fertilization is external, crude counts suggest that gravid females may release in excess of 10,000 eggs (compared to most unionids which produce hundreds of thousands to millions of glochidia) into the water column. There is no evidence of self-fertilization in this taxon, as judged from the literature and specimens examined by one of the authors (TJF).

Glochidia are typically released from the female in spring and early summer (April to July). The larvae drift passively with the plankton until they contact a suitable host teleost. Timing is critical for these larvae, as they cannot survive for long outside the female or without a host fish. Some mussels may depend on only a single fish species as a host, whereas others can parasitize many different fish species. The attachment of glochidia usually does not cause problems for the host fish (Cunjak and McGladdery 1991). If glochidia find a host fish, they attach to the gills or fins and remain attached for one to six weeks (or more or less) while transforming into a juvenile mussel. As juveniles, they drop off the fish and begin a free-living benthic life.

Likely, gonadal development takes place from the late winter to late spring, with egg and sperm release in the early summer to early fall. Only a few mature, gravid specimens have been noted. These tended to be large forms perhaps 10 or more years old. It is likely that reproduction is annual for mature individuals, so that under ideal circumstances the species is a yearly iteroparous breeder. It is probable that this species is tachytictic; the subfamily Ableminae is characterized as having a short breeding season. Other life cycle patterns are also possible, though less likely (see Dillon 2000). Strong seasonality in most of the streams in which this taxon occurs makes it unlikely that reproduction occurs in more than one period per year. Hence, the species appears to be univoltine and iteroparous. See Bauer and Wächtler (2001), McMahon and Bogan (2001) and Dillon (2000) for information on reproductive strategies in this group.

Survival

Glochidial survival in freshwater mussels is typically low, ranging between 10 and 18,000 individuals per billion glochidia that survive to the 1-2 year stage in the few taxa for which estimates have been made (Jansen *et al.*, 2001). Adults of this species seem to be comparatively short-lived, perhaps 20-30 years from growth ring counts, versus the 120 years or more for the sympatric *Margaritifera falcata*.

Physiology

Relatively little specific information is available for this taxon. *Gonidea angulata* seems to be one of a group of taxa perhaps less tolerant of siltation, nutrient enhancement, substrate shift, and of low flow régimes than are many eastern North American taxa. The taxon appears to be somewhat stenothermal, favouring cold-water oligotrophic habitats, and was so classed by Frest (1999) and Frest and Johannes (2001). However, it has shown some tolerance of increasing nutrient loads in the middle Snake River and elsewhere. In the Okanogan and Snake Rivers, it has survived decimation of native salmonid populations, which has been implicated in reducing the populations of the conspecific *Margaritiopsis falcata*. Dense populations, on the other hand, have been observed only in relatively pristine to moderately degraded streams.

Feeding may be limited under temperature extremes, during periods of relatively high sediment influx, or to avoid pollution or other habitat condition surges. The taxon commonly occurs with other cold-water stenothermal or stenotopic molluscs, such as *Margaritifera falcata*; *Anodonta californiensis*; *Juga* spp.; *Fisherola* or *Lanx* spp. and *Fluminicola* spp. All these taxa are regarded as sensitive molluscs by Frest and Johannes (1995b).

Vannote and Minshall (1982) reported that *G. angulata* was 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. Furthermore, *G. angulata* has a strongly angular, wedge-shaped shell, and the foot is commonly positioned at a right angle to the shell ridge providing for a very strong anchor.

Movements/dispersal

Unionaceans are dispersed primarily during the glochidial stage, first by currents and then by fish; hence, distribution and ecology are limited by current and fish host(s). Thus, all available habitat need not be occupied, and range may vary in size, depending upon the number and distribution potential of the fish host(s). The larval glochidia of *G. angulata* will disperse via fish movements (both upstream and downstream). Due in part to its relatively wide historical range, it is presumed that the host fish were (are) represented by more than one species and perhaps more than one family.

After leaving the fish host, the transformed glochidia, now called juveniles, typically drop to the substrate. The substrate on which they land and the water column in which the substrate occurs must be suitable for survival (i.e., low turbidity, suitable substrate for embedding, and the presence of other habitat attributes required for survival).

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 taxon, even in a relatively shallow stream. 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 individuals older than 5 years, which appear to be effectively sessile unless disturbed. Displaced individuals have been observed to reorient and rebury themselves. The taxon does not appear to migrate seasonally or during the breeding season, either in river, lakes or streams though definitive data are lacking. It appears unable to readily colonize new habitats, such as borrow pits, highway lakes, or dredged river sections, unlike the regionally more common *Anodonta oregonensis*.

Densities of adult *G. angulata* may vary considerably depending on the suitability and availability of habitat. For example, as much as 10 m or more distance separates individual *G. angulata* (1/25 m^2) in the Lower Granite Reservoir, Washington, and densities of approximately 16/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 – 183/ m^2 depending on the composition of the substrate (Vannote and Minshall 1982). The density of *G. angulata* is surely correlated to the distribution and availability of suitable habitat and it is presumed that densities of mussels will be lower in areas with poorer quality habitat than in areas with better quality habitat.

Nutrition and interspecific interactions

Gonidea angulata is an obligate filter feeder, as are most unionids. Most unionaceans filter organic debris from the water column; some may directly absorb certain nutrients, especially in the younger stages. As a result of their feeding technique, the volume of water filtered by an adult *G. angulata* is significant, which leaves them especially vulnerable to dissolved pollutants, some of which are involuntarily sequestered. For details on unionid feeding, see McMahon and Bogan (2001) and Dillon (2000).

Behaviour/adaptability

No information is available.

POPULATION SIZES AND TRENDS

Clarke (1981) collected four individuals from Vaseux Lake, British Columbia (6 August 1972) and none were gravid. More recent collections of *G. angulata* have been restricted to Okanagan Lake and Skaha Lake; however, specimens have been limited to shells and it is generally believed that this species is declining and threatened by habitat degradation and loss. Currently there are two distinct, severely fragmented populations of *G. angulta*: 1 in the Okanagan River with approximately 8 locations and another in the Kootenay River with an undetermined number of locations.

Frest and Johannes (1995b) regarded this taxon as declining in numbers at regional sites in the western U.S. and made similar comments for Idaho populations

(Frest and Johannes, 2001). Recent searches indicate that the species is absent from some streams in which it was found historically (e.g. the Yakima River) (TJF).

Gonidea angulata was recorded from 25 sites during a 1991 survey of some western U.S. states (Neitzel and Frest 1993) (Table 2). Out of more than 500 survey sites, only 25 were positive for this species (5%), with live occurrence (likely breeding populations) confirmed at only 14 (2.8%).

Between 1998 and 2001, Deixis Consultants of Seattle Washington collected *G. angulata* from a number western U.S. sites not included on Figure 3 which were scattered over the range of *G. angulata* (i.e., from southern California to the B.C.-U.S. border).

Table 2. Recent records of *G. angulata* from the Columbia River drainage system in the western U.S. and the collection in which they are held (from Neitzel and Frest).

Collection	River system and site number from Neitzel and Frest (1993)	State
Deixis	Okanogan River 9, 13	WA
Deixis	Deschutes 7, (37)*, 38, (45), (49)	OR
Deixis	Willamette 8, (19)	OR
Deixis	Owyhee 1A	OR
Deixis	Clearwater River, South Fork 22A	ID
Deixis	lower Snake River 14, (17), (18), (24), (25)	ID
Deixis	middle Snake River 9, 10, (24)	ID
Deixis	upper Snake River 38	ID
Deixis	Salmon River (1). (3), 14, 70	ID
Deixis	Weiser 3	ID

*Indicates sites where only shells were collected.

Table 3. Other confirmed sites for *G. angulata*, 1988 – 2001.

Drainage/State	River	State	No. Sites	Database Site No.
Snake River WY-ID-WA	Snake	ID	6	27, 433, 434, 500, 1147, 1148
	Owyhee	OR	2	2783
	Crooked Ck.	OR	1	4424
Pit River, CA		CA	5	1039, 1111, 1265, 1610. 5189
Umpqua R. OR		OR	2	1488, 1593
Klamath River, OR-CA	Williamson	OR	1	1860
	Sprague	OR	5	1895, 3142, 3145, 3147, 3149
	Lost	OR	2	3120, 3122

The sites listed in Table 2 represent 24 sites out of approximately 2,500 visited where *G. angulata* was detected. All 24 sites likely represent extant populations. One of the authors (TJF) estimated that the population in the Lower Granite Reservoir consisted of only a few hundred individuals while populations in the middle Snake and John Day systems certainly range into the thousands or tens of thousands of adult individuals. Population density estimates were obtained by marking out the population by snorkeling and direct visual observation; then ¼ m^2 quadrats were distributed

randomly around the population and direct counts were made (20-30 quadrats for each population). Total population size was inferred from the quadrat area results vs. the area occupied by the whole population (Okanogan, middle Snake, John Day). Because it can be difficult to identify the entire spatial extent of a given population, population estimates are given as ranges rather than precise figures. For the Lower Granite Reservoir, transects were walked along the dewatered bottom of the reservoir in relatively undisturbed areas (i.e., not disturbed by birds, mammals, or rodents) and direct counts were made along each transect. The total area of transects walked was determined, and an estimate of the population derived.

LIMITING FACTORS AND THREATS

This taxon is declining, both in terms of area occupied and number of sites and individuals. In British Columbia, species such as *G. angulata* are not threatened by direct exploitation, but by loss or degradation of their habitat. In general, unionid mussels are very sensitive to environmental changes and consequently the group contains a high percentage of endangered species in North America, including Canada (G. Mackie pers. comm.). In British Columbia, changes to the physical and chemical composition of water bodies where these mussels are known to occur can adversely affect a given population. For example, increased siltation or significant changes in water temperature as a result of natural resource extraction or human development can negatively affect the persistence of this mussel. In other areas, such as in California, extensive diversion of rivers for irrigation, hydroelectric power generation, and water supply projects has greatly reduced the range of this species.

In British Columbia, the Okanagan River is likely to undergo significant realignment in the near future. The long-term goals for the realignment are to re-establish meanders, oxbows, wetlands, and marshes along the Okanagan River and to replace salmonid habitat. In-river treatments would include the removal of in-river flood control devices and the establishment of pools, riffles, quiescent waters, and other salmonid-related habitats required for the fulfillment of salmonid life requisites. In the long-term, this realignment could prove to be beneficial for *G. angulata* in terms of greater potential for dispersal and an increase in suitable habitat. However, the short-term risks are potentially significant and activities associated with in-river construction and structure placement/removal could seriously affect existing *G. angulata* populations.

Outside British Columbia, much of the middle Snake River in Idaho is rapidly becoming eutrophic, due to agricultural runoff, fish farms, and urbanization along the river corridor. Much of the river is impounded behind a series of small dams; this is also detrimental for 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 recent (1994) landslide adjacent to the Snake River adversely affected some historic sites. For discussion of threats to Interior Columbia Basin, California, and Idaho sites for this species, see references under Frest and Johannes (1999). In the lower

Columbia River region threats to *G. angulata* include impoundments, continued siltation, eutrophication and other impacts on the few remaining sites with habitat characteristics approximating pre-impoundment conditions.

Pesticide and herbicide runoff from orchards and other agricultural operations, as well as runoff from lumber mills, and has led to increased nutrient loading in the Okanogan Physiographic Province of Washington State. Because unionids are filter feeders, they are commonly vulnerable to pollution from transition elements and heavy metals. The spread of the non-native *Corbicula* and zebra mussel *Dreissena* are also concerns. For discussion of threats to unionids, see Williams *et al*. (1993), Williams and Neves (1995), McMahon and Bogan (2001) and Dillon (2000).

Although it is uncertain which species is (are) the glochidal host for *G. angulata*, it is important to note that decline of fish populations in the lakes, rivers, and streams where *G. angulata* occurs could have detrimental effects on the distribution and occurrence of *G. angulata*. For example, the decline of a host fish species could lead to the decline of *G. angulata* populations resulting from limited dispersal of glochidia.

SPECIAL SIGNIFICANCE OF THE SPECIES

This species is the only known living taxon in this genus. The monospecific *Gonidea*, however, has an extensive fossil record in the western portions of the U.S., dating at least to the Miocene (5 million years or more: Taylor, 1988, Watters, 2001; e.g., *Gonidea coalingensis*, Taylor, 1985). It 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 forms (Lydeard et al., 1996; Watters, 2001). There may be one additional living species from Korea (Taylor, 1988), thus providing one of the most significant examples of the Asian affinities of the western North American freshwater mollusc fauna. It is particularly characteristic of the unique and sparse Pacific freshwater mussel faunal province (Taylor, 1985, 1988).

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*, *M. falcata*, and *Anodonta* species for food, tools, and ornamentation. Investigation of freshwater mussel shell middens in certain areas has detected a shift in species use from *M. falcata* to *G. angulata*, the reasons for which are unknown. However, there is reason to speculate that the aggradations of certain rivers (as mentioned in Vannote and Minshall 1982) could have resulted in an overall shift in species composition, or at least to an increase in suitable *G. angulata* habitat while limiting the availability of *M. falcata* habitat.

EXISTING PROTECTION OR OTHER STATUS

Global Status: G3
G3 = Vulnerable

Gonidea angulata is considered to be vulnerable globally either because it is very rare and local throughout its range, found only in a restricted range (even if abundant at some locations), or because of other factors making it vulnerable to extinction. G3 species typically have 21 to 100 occurrences or between 3,000 and 10,000 individuals.

Provincial Status: S1S3

The exact status of *G. angulata* in British Columbia is unknown; however, it is currently believed to be at least vulnerable and it may be endangered. More work is required to determine the extent of this taxon in British Columbia.

Red List

The provincial red list includes any indigenous species or subspecies that have, or are candidates for Extirpated, Endangered, or Threatened status in British Columbia.

Currently, this taxon has no special protection in the U.S. However, Frest and Johannes (1995b, in press) recommended it for protection on the Eastside Forest Planning Area (Interior Columbia Basin). Frest and Johannes (2001) suggested it should be monitored carefully and considered for protection if further deterioration occurs in ID populations.

SUMMARY OF STATUS REPORT

Gonidea angulata is near the northern end of its range in southern British Columbia, and it likely persists in each of the known locations in B.C., and perhaps other smaller tributaries of the Okanagan River, such as Park Rill Creek, where this species was found, although dead shell only, in 2002. The genus may be monospecific; *angulata* has or had an extensive range from southern British Columbia to southern California and much of southern Idaho and extreme northern Nevada. *Gonidea angulata* populations appear to be declining in numbers and in number of breeding individuals over much of the historic range. Proposed habitat restoration and river course realignment for the Okanagan River could negatively impact current *G. angulata* populations.

TECHNICAL SUMMARY

Gonidea angulata

Rocky Mountain Ridged Mussel Gonidée des Rocheuses

Range of occurrence in Canada: Southern British Columbia, from Penticton South in the Columbia River System. Known only from Okanagan Falls, Osoyoos Lake, Vaseaux Lake, Skaha Lake, Okanagan River, and Park Rill Creek.

Extent and Area Information	
• *Extent of occurrence (EO)(km²)*	210 km^2
• *Specify trend in EO*	Unknown
• *Are there extreme fluctuations in EO ?*	Unknown
• *Area of occupancy (AO) (km²)*	Less than EO
• *Specify trend in AO*	Unknown
• *Are there extreme fluctuations in AO ?*	Unlikely
• *Number of known or inferred locations*	Unknown, based on ½ shell. See Population Information
• *Specify trend in #*	Probably declining
• *Are there extreme fluctuations in # locations ?*	Unknown
• *Specify trend in area, extent or quality of habitat*	Probably declining in Okanagan due to habitat alteration (past and present)
Population information	
• *Generation time (average age of parents in the population)*	Unknown
• *Number of mature individuals*	Unknown
• *Total population trend:*	Unknown
• *% decline over the last/next 10 years or 3 generations.*	Unknown
• *are there extreme fluctuations in number of mature individuals (> 1 order of magnitude)?*	Unknown
• *Are there extreme fluctuations in number of mature individuals?*	Unknown
• *Is the total population severely fragmented?*	Yes
• *Specify trend in number of populations*	N/A
• *Are there extreme fluctuations in number of populations?*	N/A
• *List populations with number of mature individuals in each:*	N/A
Threats (actual or imminent threats to populations or habitats)	
Water removal, changing water levels and general habitat degradation due to pollution and agriculture in Okanagan River poses immediate threat to species.	
Rescue Effect (immigration from an outside source)	Low
Status of the outside population(s)? **USA:**	Rare in U.S.A.; ranked N3
• *Is immigration known or possible?*	Given the state of the Okanagan River (i.e., multiple dams and instream structures) it is unlikely that the fish host(s) from U.S. populations could migrate far enough upstream to effectively disperse *G. angulata* from U.S. to Canadian waters.
• *Would immigrants be adapted to survive in Canada?*	Yes
• *Is there sufficient habitat for immigrants in Canada?*	Yes
• *Is rescue from outside population likely?*	No
Quantitative Analysis	Unavailable

Status and reasons for designation

Status: Special Concern	**Alpha-numeric code:** N/A
Reasons for Designation: The distribution of this species is limited to southern British Columbia in the Okanagan and Kootenay River systems. This species has likely been impacted by the damming of the Kootenay, Columbia and Okanagan rivers and the channelization of the Okanagan River which resulted in loss or alteration of the mussel's habitat quality and extent.	
Applicability of Criteria **Criterion A** (Declining Total Population): No data available to use A criteria. **Criterion B** (Small Distribution, and Decline or Fluctuation): Uncertainties in size and trends of EO and AO and in extent and quality of habitat. **Criterion C** (Small Total Population Size and Decline): No population size data available to use C criteria. **Criterion D** (Very Small Population or Restricted Distribution): No D criteria apply and/or uncertainty in AO. **Criterion E** (Quantitative Analysis): No data available to use E criteria.	

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BIOGRAPHICAL SUMMARY OF THE REPORT WRITERS

Dr. Terrence J. Frest, PhD

Dr. Terry Frest received his PhD in 1983 from the University of Iowa. His dissertation was titled “Studies of Silurian echinoderms.” Since receiving his PhD, Dr. Frest has been an associate professor, lecturing on various topics of paleobiology and malacology. He has also consulted for various state and federal fish and wildlife organizations, providing malacological expertise. He has developed national recovery plans for rare and endangered molluscs (freshwater and terrestrial) and has conducted extensive field surveys of various freshwater and terrestrial ecosystems throughout North America. His malacogical publications date to 1981. Most recently he has been involved with the USDA Forest Service and Bureau of Land Management (BLM) and their attempts to develop and implement management strategies for rare and endangered terrestrial and freshwater molluscs as identified in the Clinton Northwest Forest Plan (ROD 1994). Dr. Frest has prepared COSEWIC-like status reports for

numerous species of freshwater and terrestrial molluscs for various agencies including the USDA Forest Service and Bureau of Land Management.

Virgil C. Hawkes, BSc, RPBio

Mr. Hawkes is a Registered Professional Biologist in British Columbia with over 8 years of experience studying the ecology of terrestrial and aquatic vertebrates and invertebrates throughout the Pacific Northwest. In addition to other work with terrestrial mammals, amphibians and reptiles, and forest-related birds, he has developed, implemented, analyzed data, and prepared technical reports for numerous projects relating to terrestrial molluscs throughout Washington, Oregon, and California. He has led field surveys to collect data on the distribution and occurrence of rare and endangered terrestrial molluscs in the Pacific Northwest, including *Hemphillia glandulosa* and *Deroceras hesperium*. Currently, Mr. Hawkes is an MSc candidate studying the effects of riparian management zones on wildlife with specific investigations into the responses of terrestrial salamanders to forestry management in the Pacific Northwest.

AUTHORITIES CONSULTED

Alvo, R. December 2001. Conservation Biologist, Parks Canada.

Cannings, S. Program Zoologist, British Columbia Conservation Data Centre.

Elner, B. December 2001. Canadian Wildlife Service, Pacific and Yukon Region.

Fraser, D. December 2001. Endangered Species Specialist, Wildlife Branch Ministry of Water, Lands and Parks.

Gaboury, M. December 2002. LGL Limited environmental research associates. 9768 Second Street, Sidney, BC. V8L 3Y8.

Golumbia, T. January 2002. Parks Canada, Gwaii Hannas National Park.

Goulet, S. December 2001. Coordinator, Aboriginal Traditional Knowledge COSEWIC Secretariat.

Gunoff, R. January 2002. Supervisor, British Columbia Parks, Haynes Point.

Lambert, P. January 2002. Curator of Invertebrates, Natural History Section, Royal British Columbia Museum. 675 Belleville Street, Victoria, British Columbia V8W 9W2 Canada.

Madill, J. January 2002. Canadian Museum of Nature.

Mcintosh, J. January 2002. Conservation Biologist, Ecosystem Secretariat, Box 280, Ucluelet, British Columbia, V0R 3A0.

Reader, B. January 2002. Parks Canada, Coastal British Columbia.

Rice, J. December 2001. Coordinator, Canadian Stock Assessment, Department of Fisheries and Oceans.

Smith, J. December 2001. National Water research Centre.

Sweeny, B.W. January 2002. Director, President, Senior Research Scientist, Stroud Water Research Center and Adjunct Professor of Biology, Department of Biology, University of Pennsylvania Stroud Water Research Center, 970 Spencer Road, Avondale, PA 19311.

Walker, I. January 2002. Professor, Limnology/Paleoecology, Okanagan University College, 3333 College Way, Kelowna, British Columbia, Canada, V1V 1V7.
Woods, J. January 2002. Parks Canada, Glacier and Mt. Revelstoke National Parks.

COLLECTIONS EXAMINED

Royal British Columbia Museum, Victoria, B.C.