COSEWIC
Assessment and Update Status Report

on the

Banff Springs Snail
Physella johnsoni

in Canada

ENDANGERED
2008

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:

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COSEWIC
Assessment Summary

Assessment Summary – April 2008

Common name
Banff Springs Snail

Scientific name
Physella johnsoni

Status
Endangered

Reason for designation
This is a Canadian endemic species with its distribution entirely within the upper reaches of fewer than 5 separate thermal springs in Banff National Park, Alberta. These springs comprise a single population, which makes it very susceptible to a catastrophic event. These short-lived animals undergo natural annual fluctuations of over two orders of magnitude. All thermal springs historically or currently occupied by this species have been impacted by human development. These snails are habitat specialists requiring a steady supply of warm thermal spring water containing a high concentration of dissolved minerals and a complex microbial community that provides food and habitat. The species and its habitat are currently protected from disturbance and destruction under *Species at Risk Act* and the *Canada National Parks Act*, but illegal activities such as soaking in thermal waters, which can crush snails and eggs and disturb habitat, are ongoing. The increase in frequency of springs drying due to climate change, which has been observed in the past decade, is believed to be an important threat to this species' survival. However, the species is closely monitored by Parks Canada.

Occurrence
Alberta

Status history
Designated Threatened in April 1997. Status re–examined and designated Endangered in May 2000 and April 2008. Last assessment based on an update status report.

COSEWIC
Executive Summary

Banff Springs Snail
Physella johnsoni

Species information

The Banff Springs Snail, *Physella johnsoni* (Clench, 1926), is a small, globe-shaped aquatic snail with a shell length up to 11 mm that coils to the left. Morphological and molecular analyses suggest that it is a valid species, although not all agree. It is suspected the species evolved within the past 3200 to 5300 years, which has resulted in limited genetic divergence from its ancestors.

Distribution

Physella johnsoni is confined to thermal springs near Banff, Alberta, within Banff National Park (BNP). The species was described in 1926 and collected from nine separate thermal springs. Two other historic sites were most likely the result of piped water or were erroneous. By 1996, the species was found living only in five thermal springs, four of which are in a high visitor-use area, the Cave and Basin National Historic Site. Two extirpated subpopulations were re-introduced, one each in 2002 and 2003 and are now self-maintaining subpopulations. These two re-introduced subpopulations are eligible for consideration in assessment of the species in accordance with COSEWIC guidelines on manipulated populations. All historic and current sites—100% of the global distribution—are found in Canada within BNP. If the seven sites are combined, all the snails live in a space similar in size to the area from the blue-line to the nearest end boards on a North American ice hockey rink.

Habitat

The Banff Springs Snail is a thermal spring habitat specialist dependent on a steady supply of warm thermal spring water (approximately 30–38°C) containing a high concentration of dissolved minerals, noticeably high levels of hydrogen sulphide and a complex microbial community that provides food and habitat structure. Most snails are found at the air-water interface, clinging to floating mats of algae, bacteria, woody debris, and leaves or on the edges of emergent rocks, concrete and rubber pool liners, and the riparian margin. Because the species is limited to thermal springs, the habitat is naturally fragmented and patchy with only the upper reaches of the thermal springs being preferred. All thermals springs historically or currently occupied by the Banff

Springs Snail have been impacted by human development although some have returned to a more natural state.

Biology

Banff Springs Snails are hermaphrodites (both sexes within the same individual). In aquaria, snails as small as 3 mm shell length (nine weeks of age) can reproduce; small (approximately 2 mm × 5 mm), crescent-shaped, clear egg capsules contain on average 12 eggs and hatch within 6 days. Reproduction in the thermal springs most likely occurs year-round with the egg capsules being attached to substrates at the air-water interface. The snails feed on the microbial community. A white, filamentous, sulphur-oxidizing bacterium is the predominant food source. Adult snails added to aquaria have lived for an additional 11 months.

Population sizes and trends

There are no historic records of snail population levels. Regular surveys since January 1996 have counted snails once every three or four weeks. Snail populations undergo annual fluctuations of greater than two orders of magnitude. Population lows occur during the summer and highs occur during the late winter. Annual lows of 30 and 43 individuals have been observed in different springs since monitoring began. In contrast, nearly 34,000 snails were counted in December 2005, the highest peak. Significantly (P<0.05) increasing yearly population lows, highs, and averages were observed but only if results from the two re-introduced subpopulations are added to the original five. Population models using seven years of data from the original five subpopulations calculated extirpation probabilities ranging from 3% to nearly 30% after 40 years. If all five original subpopulations are combined, the probability of species extinction dropped to 0%. Population modelling results must be viewed cautiously given the assumptions inherent in the models.

Limiting factors and threats

Natural (N) and human-caused threats to the species and its habitat, whether incidental to facility operations (FO) at some thermal spring complexes or through other actions by people (Hu), have been identified and ranked from most to least severe as follows: thermal water flow stoppages (N), reductions/fluctuations (N/FO), redirections (N/FO); limited or low quality habitat (N/FO); soaking and swimming (Hu); population lows and genetic inbreeding (N); trampling/local disturbance (Hu); limb-dipping (Hu); stochastic events (N); others (predation, competition, collecting, twitch-ups) (Hu/N).

Special significance of the species

The Banff Springs Snail is endemic to thermal springs in BNP, one of four thermal spring complexes in Canada that are naturally occupied by aquatic snails of the family Physidae. It is an indicator of ecosystem health and may be a keystone species. Being confined to a national park enhances its importance as national parks have been identified as being key to meeting Canada’s national and international agreements on biodiversity and species’ preservation.

Existing protection or other status designations

Physella johnsoni is listed as Endangered on Schedule 1 of the *Species at Risk Act* (SARA) and is therefore protected under provisions of SARA as well as the *National Parks Act*. It also is assigned to the highest risk category both globally (G1) and provincially (S1 in Alberta). Direction for the species’ research and recovery program since January 1996 has been provided by the Parks Canada approved Resource Management Plan. Future direction is given in the national Recovery Strategy and Action Plan.

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
(2008)

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
Canadian Wildlife Service

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Canada

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

Update
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2008

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SPECIES INFORMATION

Name and classification

Scientific name: *Physella johnsoni* (Clench, 1926)
English common name: Banff Springs Snail
French common name: Physe des fontaines de Banff

The recognized authority for the classification of aquatic molluscs in the United States and Canada is Turgeon *et al.* (1998). The current accepted classification of this species is as follows:

Phylum:	Mollusca
Class:	Gastropoda
Subclass:	Pulmonata
Order:	Basommatophora
Family:	Physidae
Subfamily:	Physinae
Genus:	*Physella*
Species:	*Physella johnsoni*

While Turgeon *et al.* (1998) assigned the English common name “striate physa” to this species, Banff Springs Snail is used by the jurisdictional authority, Parks Canada Agency, and by COSEWIC as it is more descriptive of the snail’s distribution and habitat. The original scientific name, *Physa johnsoni,* was used by Clarke (1973, 1981) in both his monograph and book on molluscs of Canada. Te’s (1978) revision of the family resulted in renaming most of the *Physa* as *Physella*, although others (Dillon 2000; Wethington and Guralnick 2004) still use *Physa*. There are also differing opinions on whether *Physella johnsoni* is a synonym of a related species, *P. gyrina,* a generalist and the most widely distributed physid in Canada (see **Morphological** and **Genetic descriptions**).

Morphological description

All members of the Physidae are sinistral (coiled to the left). When holding the shell with the spire (the point or apex) up, the aperture (opening where the snail’s body protrudes) will be on the left. All other cone-shaped North American freshwater snail families are dextral, with the aperture on the right.

The original description given by Clench (1926) and reproduced in Clarke (1973) is as follows:

> "Shell sinistral, small, globose, thin. Color dark reddish horn, sometimes faintly striated. Whorls 4½ to 5, convex and well rounded, nuclear whorl darker in color. Spire rather short, terminating in an acute apex. Aperture well rounded, flaring slightly at the base. Palatal lip very thin, rarely labiate. Parietal lip of a thin deposit only on body whorl. Columella rather narrow, not twisted, inclined toward the left and not abruptly terminating in the body whorl but gradually continuing the general contour. Suture very well impressed, slightly indented. Sculpture of very fine growth lines but no cross striae. The loss of the periostracum on some of the most prominent growth lines gives it the appearance of striations as noted above. Varicose bands rare and most noticeable when seen from within the aperture."

Te (1978) describes the shell as small, elongate-ovate in shape, with heavy and uneven growth lines (Figure 1). While the maximum published shell length is 8.8 mm (Clarke 1973) living animals with shells up to 11 mm in length have been observed with the animals ranging in colour from light-brown to black (Lepitzki unpubl. data). Lepitzki (1998) measured shells of live *P. johnsoni* (n=157*), Physella gyrina* (n=168) and another physid, most likely *Physa megalochlamys* (n=80), using an ocular micrometer at 10x magnification. The specimens had been collected from Banff National Park in 1997 for allozyme and mtDNA analyses. The *P. johnsoni* had significantly (P<0.05 for pairwise comparisons) larger shell width to length ($F_{2,402}$=63.795, P<0.001) and spire to length ($F_{2,402}$=6.759, P=0.001) ratios than the other two species. The maximum *P. johnsoni* shell length measured was 9.2 mm.

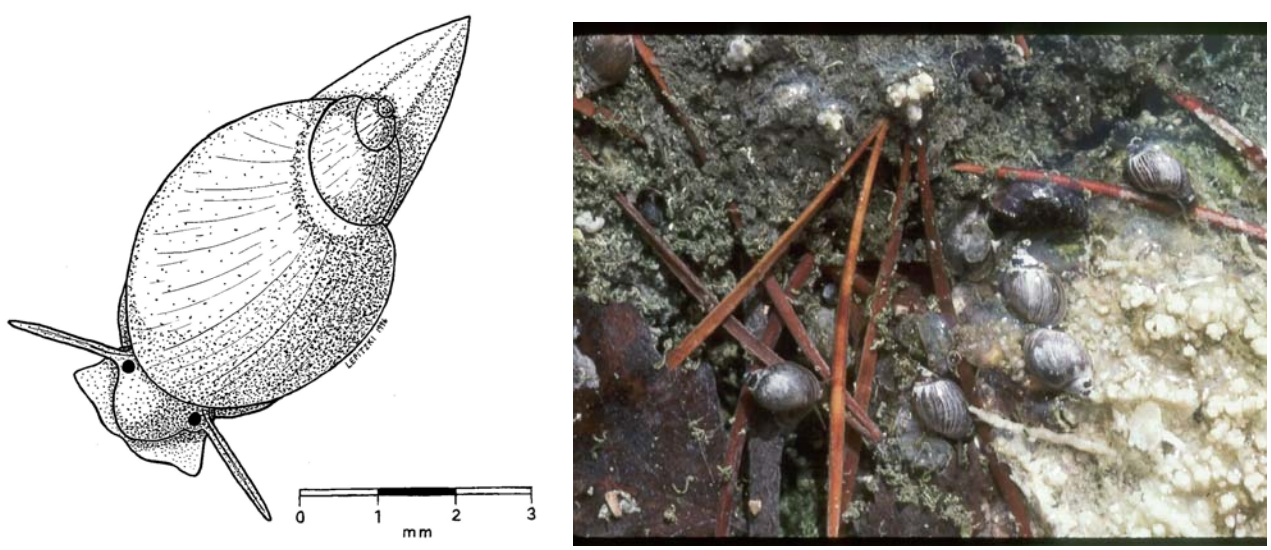

Figure 1. Line drawing and photograph of *Physella johnsoni*, the Banff Springs Snail. (Drawing credit: D.A.W. Lepitzki, photograph credit: B.M. Lepitzki)

In addition to shell morphology, penial morphology also is used in the classification of physids. Te (1978) found that the two *P. johnsoni* he dissected had Var-1 and Var-2 of the type-c penial complex, which placed it within the *Physa acuta* group. A type-c penial complex is characterized by the presence of a preputial gland and a single-parted non-glandular penial sheath. In contrast, Wethington and Guralnick (2004) placed *P. johnsoni* within the *P*. *gyrina* group, or Te's (1978) type-b penial complex, characterized by a preputial gland and a two-parted penial sheath having both a glandular and non-glandular component. Taylor (2003) also places *P. johnsoni* within the *P*. *gyrina* group, having a bipartite penial sheath. However, Taylor did not personally study or verify morphologically any *P. johnsoni* or any *P. gyrina* specimens, so his rationale for placing *P. johnsoni* within the *P*. *gyrina* group is uncertain. Lepitzki (unpubl.) dissected two additional *P. johnsoni* and they had type-b, *P. gyrina*-group penial morphology (Figure 2).

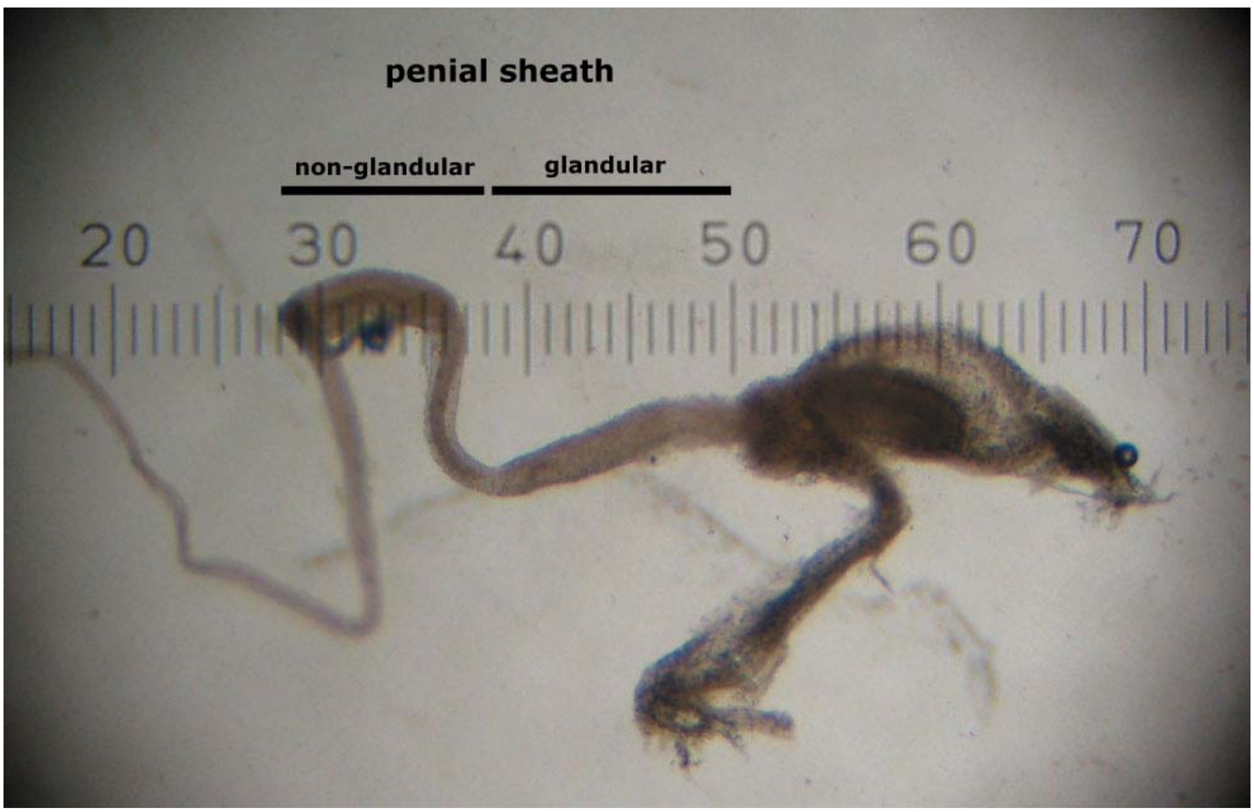

Figure 2. Photograph of penial morphology of *Physella johnsoni* , the Banff Springs Snail, collected from Lower Middle Spring, Banff National Park, June or July 2002 and maintained in a thermal water flow-through aquarium at the C&BNHS until the snail's natural death on 8 February 2003. The bi-partite penial sheath is easily distinguished with non-glandular and glandular portions. Each ocular unit is 100 microns. (Photograph credit: D.A.W. Lepitzki)

Genetic description

Allozyme and mtDNA studies have been done on the Banff Springs Snail. Hebert (1997), using the specimens collected and measured by Lepitzki (1998), screened 20 individuals from each of five subpopulations for allozyme variation at 12 loci: *Apk, Fum, Got-m, Got-s, Gpi, Idh, Ldh, Mdh-m, Mdh-s, Mpi, Pgm-1*, and *Pgm-2*. He states in his unpublished report, to which Remigio *et al.* (2001) refer, that no allozyme variation was detected at four of the loci: *Apk, Got-m, Mpi*, and *Pgm-2*. Levels of intraspecific polymorphism also were low with no variation detected in *P. megalochlamys*. Variation in *P. gyrina* and *P. johnsoni* was restricted to the *Idh* locus. Despite limited polymorphism, marked genetic divergence was apparent among the taxa. *Physa megalochlamys* was easily distinguished from the two *Physella* by its diagnostic $Gpi^{1.32}$ and $Fum^{1.16}$ alleles. Populations of *P. johnsoni* and *P. gyrina* showed allelic substitutions at *Got-s* and at both *Mdh* loci. Hebert (1997) concluded that "genetic distance analysis confirmed that conspecific populations showed close genetic affinity, while there was marked divergence among the 3 taxa". His unpublished genetic distance figure is reproduced as Figure 3. He also states that each of the species examined showed limited polymorphism but that this was not unexpected as these gastropods are hermaphrodites, capable of self-fertilization. Populations of each species showed limited genetic divergence but there was marked divergence among species and "diagnostic allozyme markers separate each of the species, permitting their reliable discrimination." He concluded that his results "makes it very unlikely that *P. johnsoni* is simply a thermal spring ecotype of *P. gyrina*" and that the "results support the need to treat *P. johnsoni* as an endemic species with a substantial history of evolutionary divergence from *P. gyrina*."

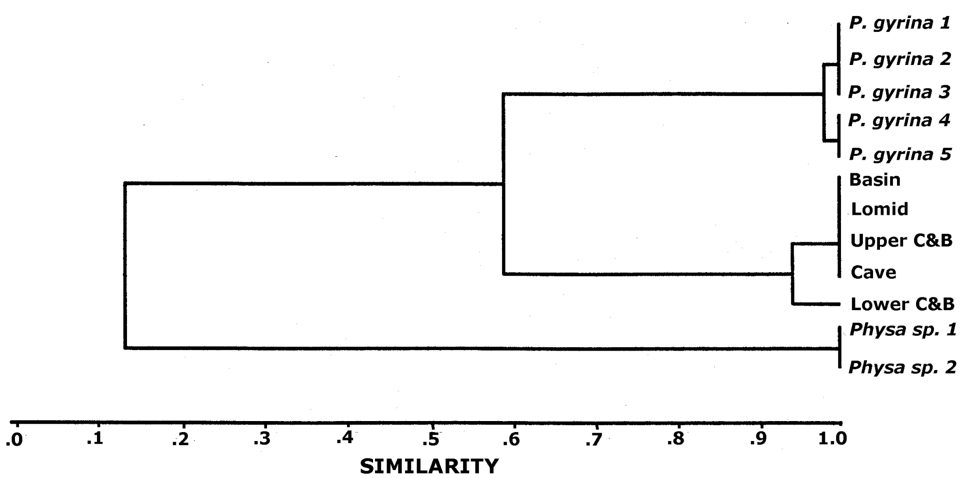

Figure 3. UPGMA of Nei's unbiased genetic distances among three species of physid snails from Banff National Park, as shown by allozyme analyses. The snails from the Basin, Lomid (=Lower Middle), Upper C&B, Cave, and Lower C&B were *P. johnsoni*. The *Physa* sp. 1 and *Physa* sp. 2 were most likely *Physa megalochlamys* and were collected from the Hay Meadow and Rat Hole Ponds, between 2nd and 3rd Vermilion Lakes. *Physella gyrina* 1 through 5 were collected from: 1 = C&B marsh; 2 = Vermilion Cool Springs; 3 = 5-mile Pond; 4 = Herbert Lake; and 5 = Muleshoe Lake. Reproduced with permission from Hebert (1997).

Figure 4. Global distribution of the Banff Springs Snail, *Physella johnsoni*. The point indicates Banff National Park, Alberta, Canada.

The same snail collection was then subjected to mtDNA analyses. Remigio *et al.* (2001) sequenced the 16S and COI mitochondrial genes from a single snail from each of the populations (two *P. johnsoni* were sequenced from one subpopulation, Cave Spring, and found to have identical sequences so only one was used in the analyses). They found that the genetic distinctiveness between *P. gyrina* and *P. johnsoni* was apparent only in the parsimony analysis of the combined 16S and COI data and individuals from the Cave Spring always clustered away from the other samples of *P. johnsoni*.

Wethington and Guralnick (2004) then used the sequences of Remigio *et al.* (2001) available through GenBank. The scope of their study expanded beyond that of Remigio *et al.* (2001) by including other physids collected from thermal springs and cave environments throughout the United States. Two additional specimens of *P. johnsoni* collected from the type locality by Lepitzki in August 2001 also were sequenced and dissected for penial morphology. Their dissections and mtDNA analyses clearly placed *P. johnsoni* within the *P. gyrina* group. They concluded that *P. johnsoni*, because it did not form a distinct monophyletic group, was indistinguishable from other members of the western U.S. within the *P. gyrin*a group. The outlier was from the Cave Spring subpopulation. A *P. gyrina* individual from the type locality in Iowa also was included in the *P. johnsoni* group along with the two additional specimens collected from the type locality by Lepitzki. Sampling is acknowledged as an explanation of *P. johnsoni* not forming a monophyletic group (n=8 *P. johnsoni*: 6 from Remigio *et al.* 2001 and 2 additional in Wethington and Guralnick 2004). The three other physids in the *P*. *gyrina* group collected from thermal springs all formed monophyletic groups but only two individuals of each species were sequenced. If more individuals of other species or more subpopulations of each species were sequenced, they might not be monophyletic either.

Another explanation for the small level of genetic differentiation between *P. gyrina* and *P. johnsoni* is the young age of *P. johnsoni*. Remigio *et al.* (2001) concluded that *P. gyrina* and *P. johnsoni* were distinct species that had only separated since the most recent ice age retreated, approximately 10,000 years ago. Newer evidence, from ^{14}C age dating, suggests that the thermal spring habitat of *P. johnsoni* is even younger and only around 3200 to 5300 years old (Grasby *et al.* 2003). This short evolutionary history may offer an explanation why Wethington and Guralnick (2004) concluded that *P. johnsoni* is “indistinguishable” from *P. gyrina* and dispute the conclusions of Hebert (1997) and Remigio *et al.* (2001) that *P. johnsoni* is a valid species.

The latest phylogeny proposed by Wethington and Lydeard (2007), analysing two mitochondrial DNA sequences (16S and CO1) and comparing penis morphology, supports the recognition of physids with type-b penial morphology as a clade consisting of two species, and lumps seven different taxa, including *P. wrighti* and *P. johnsoni,* under *P. gyrina*.

Designatable units

No designatable units below the species level exist. If *P. johnsoni* were synonymized with *P. gyrina,* the Banff Springs population would be available for consideration as a designatable unit of *P. gyrina* due to its biogeographical distinctness and its biological adaptations to the harsh thermal spring environment. These hotwater specialist snails may represent unique and important ecological and/or evolutionary units (i.e., DUs under SARA) that still warrant protection. This can be further investigated using molecular markers that evolve more quickly than mtDNA markers (i.e., microsatellite DNA).

DISTRIBUTION

Global and Canadian range

Physella johnsoni is endemic and restricted to a few thermal springs. All these springs occur within the southern Canadian Rocky Mountains immediately adjacent to the Town of Banff within Banff National Park (BNP), Alberta (Figures 4 and 5). Burch (1989) includes Alberta, Montana, Wyoming, and Colorado in the species' distribution, most likely from museum specimens, but is erroneous. Others also do not list *P. johnsoni* as occurring in Montana (NatureServe 2006), Colorado (Wu 1989), or Wyoming (Wu and Beetle 1995). All historic and current subpopulations occur in Canada.

The type specimens were collected from "middle spring, Hot Sulphur Springs, Banff, Alberta" (Clench 1926) (Figure 5). A second lot consisting of bleached shells only was "collected by E.C. Case in a deposit below the swimming basin" (Clench 1926). Clarke (1973) lists the species as having been collected from "Upper Hot Springs, Banff, Alta. (1927, T. Ulke). Middle Spring, Hot Sulphur Springs, Banff, Alta. (type lot)" and "Kidney Spring, Hot Sulphur Springs; Cave and Basin; and Cold Spring, Vermilion Lake, Banff (all Jan. 1927 and Jan. 1929, O. Bryant)." As there are a number of individual springs in "Middle Springs" and at the "Cave and Basin" (Figure 5), it is uncertain which specific springs were inhabited by the snail. Furthermore, Bryant's 1927 and 1929 dates of collection are likely erroneous as specimens were received at the Museum of Comparative Zoology, Harvard University (Cambridge, MA) by Clench in August 1926 and therefore must have been collected prior to 1926 (Baldinger pers. comm. 2001; Clarke pers. comm. 2001).

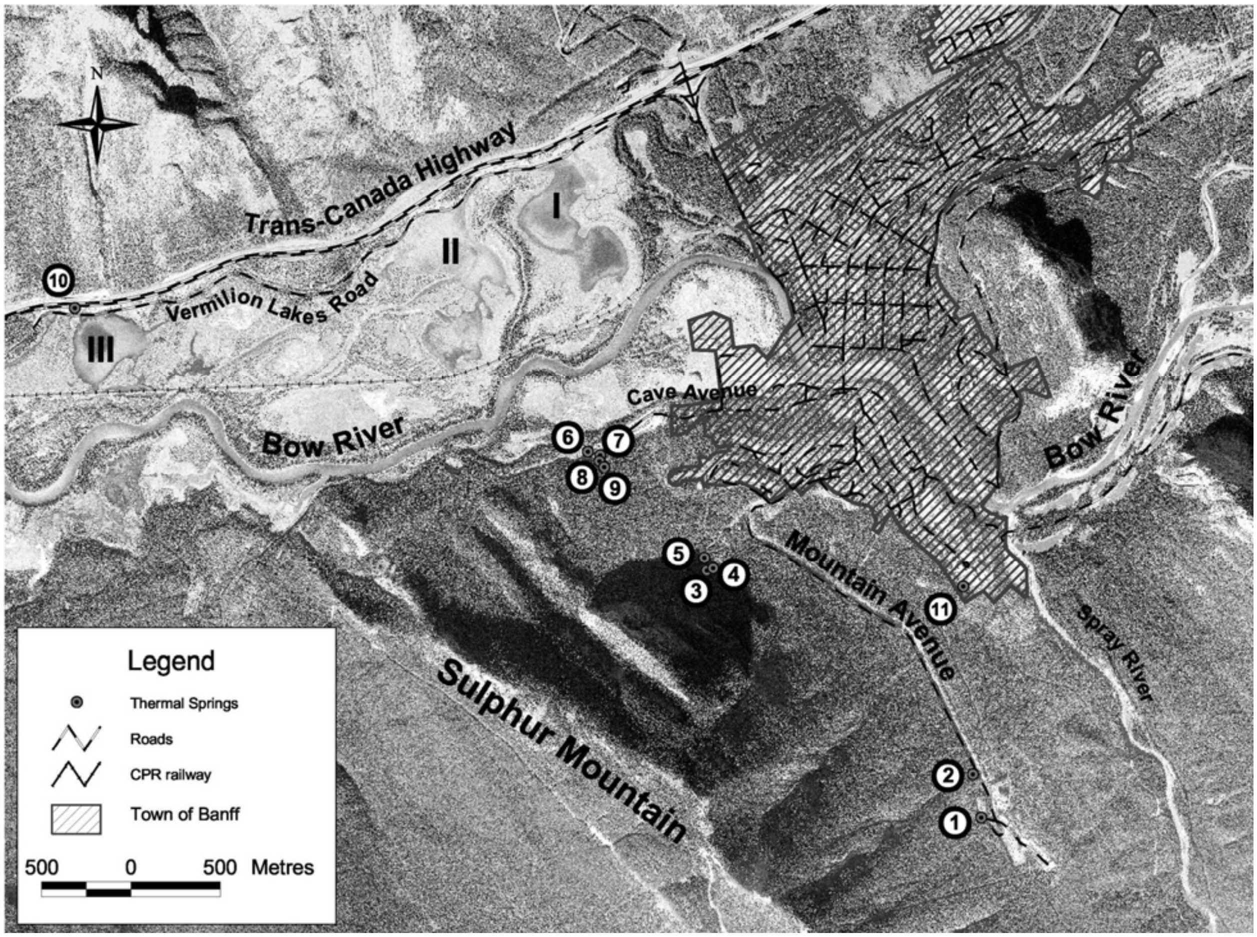

Figure 5. Historic distribution of *Physella johnsoni*, the Banff Springs Snail, in thermal springs near the Town of Banff, Banff National Park, Alberta. 1 is the Upper Hot Spring (snail extirpated); 2 is the Kidney Spring (snail re-introduced November 2003); 3, 4, and 5 are the Gord's (snail extirpated), Upper Middle (snail re-introduced November 2002), and Lower Middle (snail extant) Springs; 6, 7, 8, and 9 are the Basin, Cave, Lower C&B and Upper C&B (snail extant in all) Springs of the Cave and Basin National Historic Site; 10 is the Vermilion Cool Springs (currently occupied by *Physella gyrina*); 11 is the Banff Springs Hotel Site (most likely from piped water, currently site no longer exists); I, II, and III are the Vermilion Lakes. Reproduced with permission from Lepitzki and Pacas (2007).

Since the original collections, the species has been collected twice: in an "Outlet of Middle Spring, 0.8 mi E of Middle Spring (i.e. 300 yds S of Banff Springs Hotel)" by H.D. Athearn, on 23 July 1965 (Clarke 1973) and from "Middle Springs" on 1 October 1975 (Iredale pers. comm. 1975). To Clarke's knowledge the site description of the outlet stream is accurate (Clarke pers. comm. 1996); Athearn has confirmed the site (Athearn pers. comm. 1996). As no other springs were examined in 1965 (Athearn pers. comm. 1996), it is uncertain how many of the original sites continued to persist during Athearn's collecting trip.

By 1996, the species still inhabited five of the historic sites at two locations: Lower Middle and the four springs at the Cave and Basin National Historic Site (C&BNHS) – Cave, Basin, Upper C&B, and Lower C&B (Lepitzki 1997a,b). All of these individually separate thermal springs are regarded as representing a single population, although snail movement between thermal springs is extremely unlikely and would require movement across dry land unless the snails are transported by birds or anthropogenically, e.g., through pipes or in containers (see **Dispersal/migration**). The outflow stream near the Banff Springs Hotel no longer exists and is currently under a parking lot. It is also suspected that this site resulted from thermal spring water piped from Kidney Spring to the Banff Springs Hotel (Lepitzki pers. obs.; Van Everdingen 1972), and not from the Middle Springs as the latter outflow stream is north of the hotel.

Numerous shells of *P. johnsoni* are found along the outflow stream of the Upper Middle Springs (Figure 5) (Lepitzki pers. obs.) suggesting that the species was recently present prior to 1996. Fewer than 10 physid shells, most likely *P. johnsoni*, have been found by Lepitzki in Gord's Spring, a previously undescribed thermal spring in Middle Springs area (Figure 5). Fewer than 10 shells also have been found at Kidney Spring and fewer than five shells have been found embedded in tufa at the Upper Hot Spring within the last 10 years, suggesting that these subpopulations may have been extirpated some time ago. It is also uncertain whether live snails or empty shells were collected at the Upper Hot in the 1920s. Live physids are presently found at the Cool Springs at Third Vermilion Lake (Figure 5), but they are *Physella gyrina* (Lepitzki 1997a,b; Hebert 1997; Remigio *et al.* 2001). It is questionable whether *P. johnsoni* ever existed at the Cool Springs, given the current occupancy by *P. gyrina* and the differences in water physicochemistry between the Cool Springs and those springs currently containing *P. johnsoni* (see **Habitat requirements**).

It is extremely unlikely that unknown localities of the snail exist, given human fascination with thermal springs and human history and extensive use of BNP. All known thermal springs along the Sulphur Mountain thrust fault (Grasby and Hutcheon 2001; Grasby and Lepitzki 2002), the point of origin for the Sulphur Mountain thermal springs (Figure 5), including Forty Mile Spring (between Mounts Brewster and Norquay to the north) and six previously undescribed cooler thermal springs in the Middle Springs area (Lepitzki unpubl. data) have been examined for snails (Lepitzki pers. obs.). Lepitzki (unpubl. data) has also examined Miette Hot Springs in Jasper National Park (Grasby *et al.* 2000) and others have examined Mist Mountain Spring (Grasby *et al.* 2000) and no snails were found (Lepitzki unpubl. data; Grasby pers. comm. 2001).

The extent of occurrence (EO) has been calculated using Oziexplorer GPS Mapping Software (D & L Software Pty Ltd Australia 2002) on GPS points recorded with a hand-held GPS receiver (±10 m) (Figure 5). If all historic sites are included in the polygon (COSEWIC O&P Manual 2006) except the Banff Springs Hotel site and Vermilion Cool Springs, an EO of 345,409 sq. m. (=0.345 km²) results. As of 1996, the EO had declined to 32,579 m² (=0.0326 km²) with extant subpopulations being found at only five springs. As of 2006, two subpopulations have been re-introduced and are self-maintaining (Upper Middle and Kidney, see **POPULATION SIZES AND TRENDS**), and the EO increased to 176,755 sq. m. (=0.177 km²). If the snail is ever re-introduced at the Upper Hot and Gord's Springs (Lepitzki and Pacas 2007), the EO would revert to historic levels.

Not only does *P. johnsoni* have a severely restricted distribution, as shown by the small EO, it also has a marked microdistribution within each spring (Lepitzki 2002a) (see next section). Area of Occupancy (AO) was calculated to be 5 km² using a 1 × 1 km grid and including the two re-introduced subpopulations (A. Filion, April 2008). The actual, more biologically defensible AO was calculated to be 595.4 m². (=0.0006 km²) (Table 1). The area between the blue line and the nearest end boards of a North American ice hockey rink (595.25 m², Wikipedia 2006) is similar. This occupied habitat is the Critical Habitat for the snail (Lepitzki and Pacas 2007).

Table 1. Area of occupancy* and summary of Banff Springs Snail subpopulations, January 1996 through May 2007. Upper Middle and Kidney Spring subpopulations were re-introduced in November 2002 and 2003, respectively. The Basin population includes the fall 2005 augmented Basin outflow stream snails.**

Spring	Area of occupancy (sq. m.)	10+ year population minimum	10+ year population maximum
Kidney	25.6	8	8,852
Upper Middle	176.2	16	16,247
Lower Middle	22.4	30	4,221
Cave	190.4	474	5,657
Basin	80.5	162	10,242
Upper C&B	31.3	147	3,268
Lower C&B	69.0	43	4,619
Original 5 combined	393.6	1561	16,427
Original 5 + 2 re-introduced	595.4	1561	33,915

*Area of occupancy (AO) was calculated using SigmaScan Pro (Systat 2004) on detailed maps created with tape measure and compass. The two-dimensional surface area of all microsites where at least one *P. johnsoni* has been observed from 1996 through 2006 was measured three times; the average of the total of all microsites in each spring is shown.

**Subpopulation counts are total individuals, most of which are mature individuals.

HABITAT

Habitat requirements

Canadian thermal springs are confined to the mountainous areas of the Cordilleran regions of Alberta, British Columbia, Yukon, and the Northwest Territories (Van Everdingen 1991). They are fragile, and small-scale ecosystems with rare micro-climatic conditions created by and wholly dependent on local geothermal activity and can be considered harsh environments with high temperatures, high concentrations of dissolved minerals, and low levels of dissolved oxygen (Brues 1924, 1927). With the exception of the Vermilion Cool Springs, the Sulphur Mountain thermal springs occur along the Sulphur Mountain thrust fault on an elevational gradient from the Upper Hot to the Cave and Basin (Figure 5). The Vermilion Cool Springs occur along the Bourgeau thrust (Grasby and Lepitzki 2002). Water in the form of rain and snow falling on neighbouring Mount Rundle is believed to be the source for the Sulphur Mountain thermal springs (Grasby and Lepitzki 2002). This meteorological water circulates to a depth of approximately 3.2 km; heat and dissolved minerals are added to the water from the surrounding rock (Grasby and Lepitzki 2002). In general, the highest elevation springs are the hottest (Upper Hot) with maximum temperature declining along the elevation gradient (Figure 6). Seasonal changes occur in water physicochemistry with the magnitude of the change generally largest at the highest elevation springs. The springs reach their maximum temperature during the winter (Figure 7) when infiltration from melting snow and ice is reduced. During spring run-off, additional shallow ground water results in increased flow rate, pH and dissolved oxygen levels and decreased water temperature, conductivity and hydrogen sulphide levels (Figure 8). The seasonal changes in water physicochemistry result in seasonal changes in the microbial community inhabiting the springs (Van Everdingen 1970; Grasby and Lepitzki 2002).

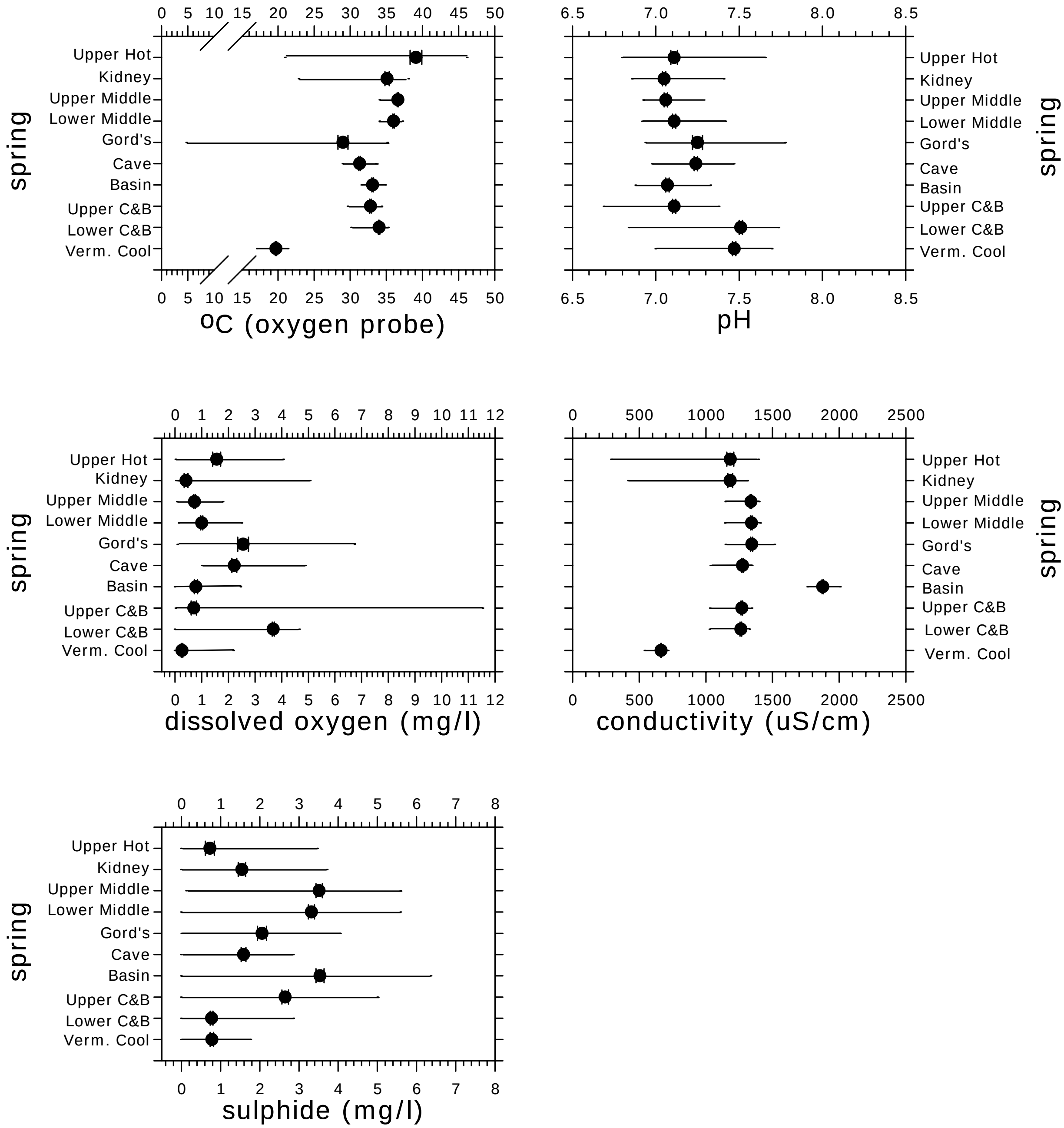

Figure 6. Water physicochemistry in the origins of the thermal springs historically inhabited by *Physella johnsoni*. Means, standard errors of the mean, and range of parameters measured from March 1998 through December 2005 by a hand-held multimeter and portable spectrophotometer (sulphide) during snail surveys are shown; measurements in Gord's Pool Spring began in January 2001. Large ranges result from springs drying and/or seasonal fluctuations.

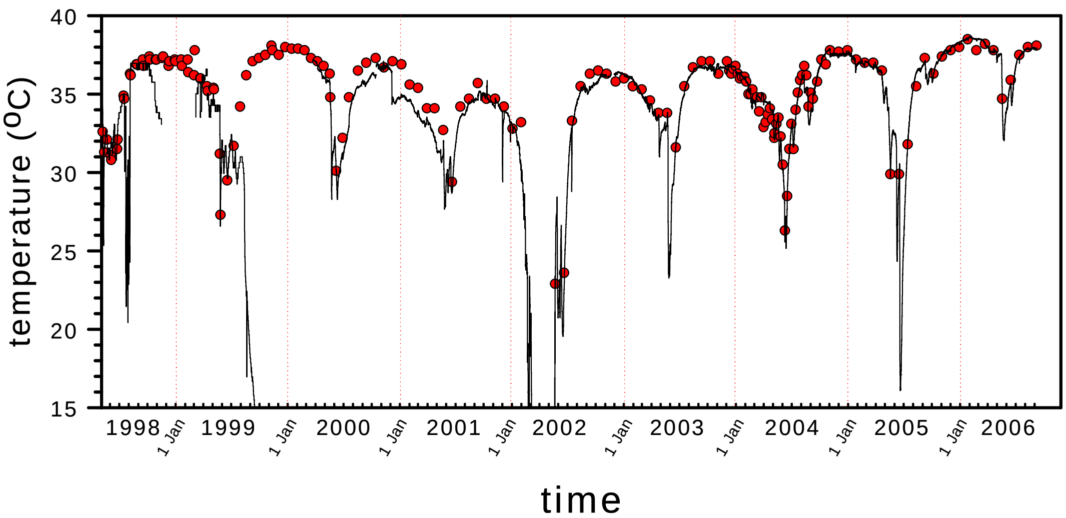

Figure 7. Water temperature at Kidney Spring origin measured hourly by automatic temperature loggers (solid line) and during snail surveys (dots), May 1998 through 9 September 2006. The dips in the logger traces in 1998 and 1999 are erroneous, the first dip in 1998 is the result of the logger being removed from the water and the others are due to malfunctions. The dip early in 2002 is the result of the spring drying.

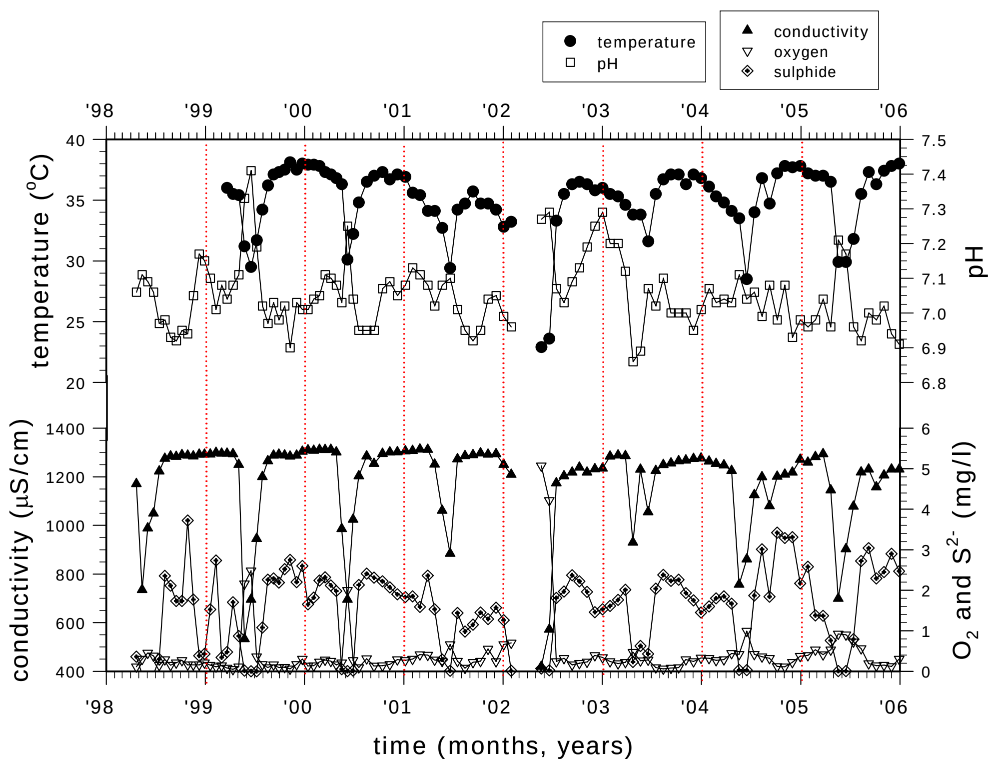

Figure 8. Water physicochemistry of Kidney Spring origin measured with a hand-held multimeter and portable spectrophotometer (sulphide), March 1998 through December 2005. Lack of measurements early in 2002 result from the spring drying.

Spatial changes also occur along the course of the thermal spring from the origin pool down the outflow stream in both the microbial community (Lepitzki pers. obs.; Londry 2005a, b) and water physicochemistry-water temperature and sulphide decline, while pH and dissolved oxygen increase (Lepitzki 2002a; Londry 2005a, b). These biotic and abiotic gradients may explain the microdistribution of the snail whereby most of the snails for most of the year are found at or near the origin pools of the various springs (Figure 9). As such, the Banff Springs Snail is considered a thermal spring habitat specialist dependent on a steady supply of warm thermal spring water containing a high concentration of dissolved minerals, noticeably high levels of hydrogen sulphide and a complex microbial community that provides food and habitat structure. Most of the snails are found at the air-water interface, clinging to floating mats of algae, bacteria, woody debris and leaves or on the edges of emergent rocks, concrete and rubber pool liners, and the riparian margin. While the upper reaches and origin pools of the thermal spring are the preferred, natural habitat for the species, the *P. johnsoni* has been successfully maintained in natural thermal spring water in flow-through aquaria with and without the addition of fish food flakes and also in warmed tap-water where the snails fed on fish food flakes (Lepitzki 2003a,b, 2004; see **Adaptability**).

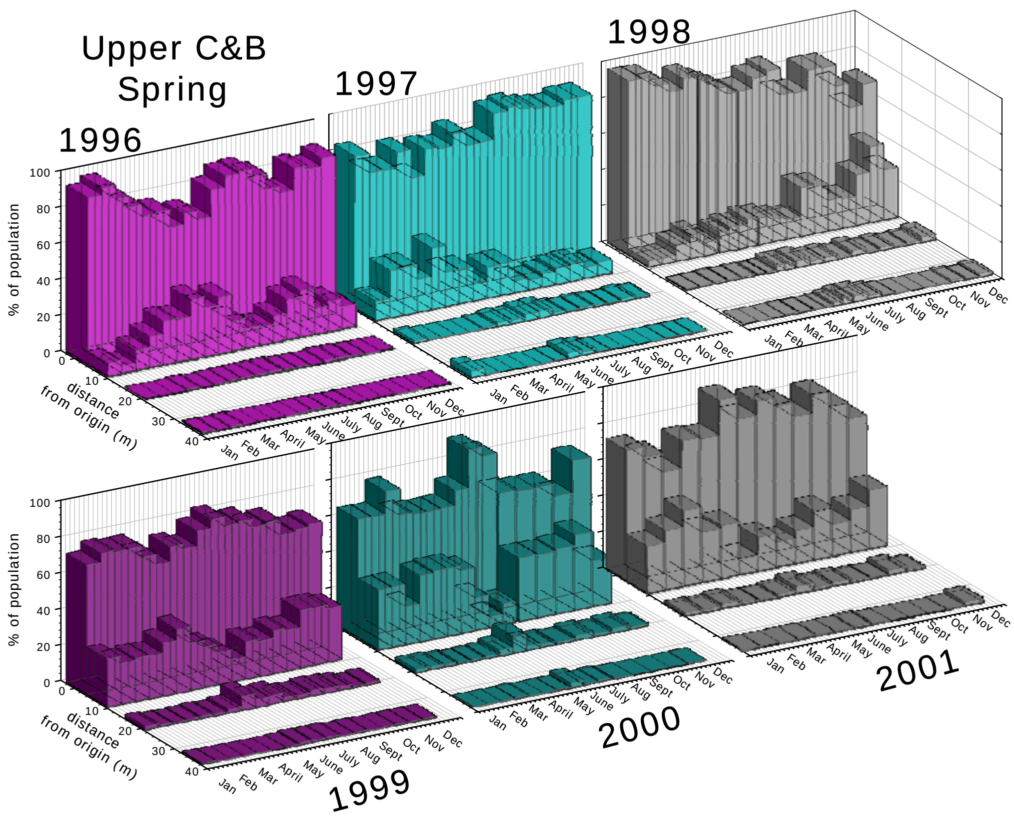

Figure 9. Microdistribution of *Physella johnsoni* at the Upper C&B Spring, 1996 through 2001. Snails were counted in four microsites from the origin pool and down the outflow stream.

Because the species is limited to thermal springs, the habitat is naturally fragmented and patchy with only the upper reaches being preferred. In general, diversity of other thermal spring dependent flora and fauna increases with distance from the thermal spring origin pool. Recent survey work has identified two rare damselflies (Rice 2002; Acorn 2004; Hornung 2005; Hornung and Pacas 2006), and a number of rare mosses and liverworts (Krieger 2003). There is also a high diversity of algae (26 genera, representing between 40 and 50 species; Hebben 2003), and novel strains of bacteria, many of which are potentially endemic to the Banff thermal springs (Yurkov and Bilyj 2005). At least two vascular plants (hot springs millet *Panicum acuminatum*; bracken fern *Pteridium aquilinum*) appear to have been extirpated, both having last been seen at the C&BNHS in 1899 (Wallis 2002). A fish subspecies (Banff Longnose Dace *Rhinichthys cataractae smithi*), endemic to the springs at the C&BNHS, is extinct (COSEWIC 2006).

The Banff Springs Snail has a certain tolerance for natural disturbance and is able to survive the natural seasonal fluctuations in water flow and physicochemistry and the natural cycles in the microbial community. The species has been able to withstand redevelopment at the C&BNHS (see **Habitat trends**); however, in the 70 years since the species has been known to science, at least half of the historical sites have been extirpated even though all were within a national park.

Habitat trends

Water physicochemistry of some of the Sulphur Mountain thermal springs was measured as early as 1916 and 1917 (Satterly and Elworthy 1917; Elworthy 1918). The temperatures recorded near the turn of the last century fall within the ranges of the more recent measurements. In general, temperature and chemistry of individual springs are constant through time (Grasby *et al.* 2000) although in a geological context, spring extinction also occurs. Brues (1928) found evidence of the vast extent and enormous size of earlier springs, now extinct, in areas still containing springs. Even within the Middle Springs area, there is evidence of at least one spring having permanently ceased flowing, possibly centuries ago (Lepitzki pers. obs.). The large tufa boulders near the current origin of the Upper C&B are evidence of a collapsed cave (Grasby *et al.* 2003). In addition, the extensive tufa mound at the Upper Hot may suggest that overall flow was greater or more dispersed than it is today although piping and impoundment of water sources has also contributed to the prolific vegetation growth on the mound (Grasby and Lepitzki 2002).

While it is normal for flow rates to decrease as underground reservoirs are depleted of water during late winter and early spring (Van Everdingen 1970, 1972; Grasby and Lepitzki 2002), the frequency of thermal spring drying has increased. The only historically recorded instance of any Sulphur Mountain thermal spring drying is the Upper Hot, when no water flowed from 12 March through 11 May 1923 (Elworthy 1926; Warren 1927). Since 1996, the Upper Hot Spring dried during eight winters (Figure 10) with the flow stoppage ranging from approximately one to 32 weeks in duration (Grasby and Lepitzki 2002, Lepitzki unpubl. data). A lower than normal amount of precipitation in

1922 was the proposed cause of the 1923 flow stoppage (Warren 1927). Similarly, below normal precipitation may be the cause of the recent flow anomalies (Grasby and Lepitzki 2002). The lowest precipitation year on record (2001) (Grasby and Lepitzki 2002) was followed by the most extensive period of drying at the Upper Hot, and, for the first known instance, the drying of Kidney Spring (Lepitzki and Pacas 2003). While it is expected that the topographically highest springs along the Sulphur thrust fault will stop flowing first (Grasby and Lepitzki 2002), inexplicably, the Upper Middle Springs dried for at least 12 weeks during the winter of 1995-1996 (Grasby and Lepitzki 2002) and Gord's Pool Spring dried during the fall and winter of 2005-2006 and 2006-2007 when all other Sulphur Mountain thermal springs continued to flow (Figure 10).

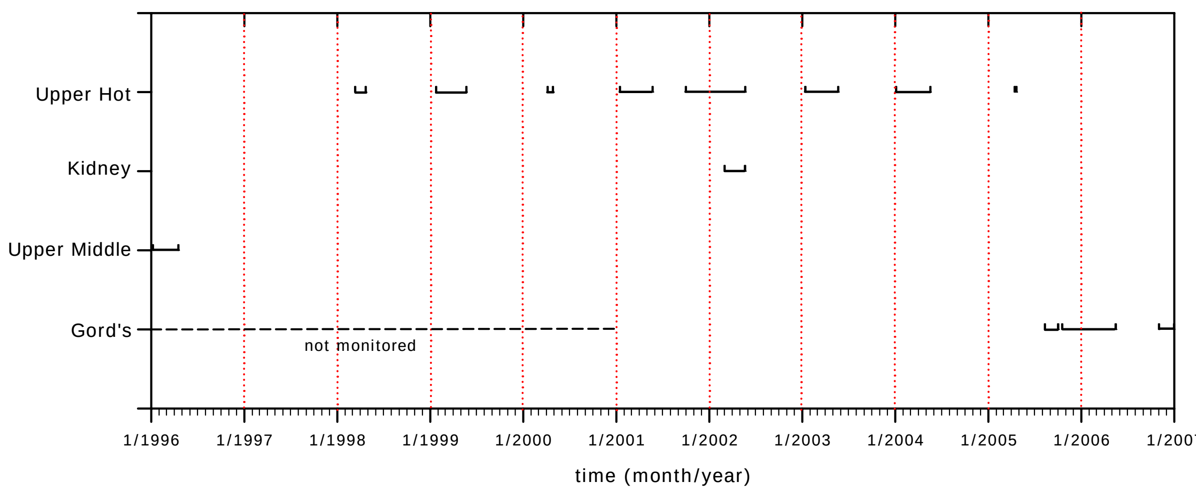

Figure 10. Timing and duration of thermal spring flow stoppages, 1 January 1996 through 31 December 2006, Banff National Park. The only previously known instance of any Sulphur Mountain thermal spring drying was the Upper Hot which dried from 12 March to 11 May 1923. The line between the uprights indicates when no thermal spring water flowed as shown by observation and temperature logger data. Monitoring of Gord's did not begin until January 2001.

Climate change projections for BNP predict a decrease in summer precipitation and an increase in winter and spring precipitation (Scott and Suffling 2000; Scott and Jones 2005). Consequently, water flow of Sulphur Mountain thermal springs is expected to remain near current levels or decrease slightly (Scott and Suffling 2000). If the past 10 years are any indication of the future under the climate change predictions, continued flow anomalies, including cessations, are expected.

All thermal springs historically or currently occupied by the Banff Springs Snail have been impacted by human development, although some have returned to a more natural state. The Upper Hot Spring is the source for the only remaining thermal spring public bathing facility in BNP and has been continually used as such since at least 1918 (Van Everdingen 1972). Nearly 300,000 people bathed at the Upper Hot in fiscal year 1995/1996 (Davidson pers. comm. 1996); current numbers are suspected to be similar. Originally, several spring outlets formed the large tufa mound at the Upper Hot but in the late 1800s water was collected and piped into an underground concrete cistern (Grasby and Lepitzki 2002). Only when excess water collects in the cistern or it is too cool to be used in the bathing pool, is water allowed to flow on the surface above Mountain Avenue before joining used, chlorinated, pool water and surfacing once again below Mountain Avenue into the outflow stream. The outflow stream eventually empties into the Spray River (Figure 5). Extensive renovations and redevelopment of the main bathing building and pool occurred in 1996. Trails between the Upper Hot and the Sulphur Mountain gondola parking lot also were formalized and a wooden, horizontal pole fence and boardwalk constructed above the outflow stream above Mountain Avenue. Visitors are encouraged to touch the natural thermal water by a cut-out section in the fence on their walk to the bathing pool.

The Kidney Spring, approximately 200 m north of the Upper Hot (Figure 5), was impounded into a small concrete cistern (~0.87 m x 0.87 m) and piped to the Banff Springs Hotel for use in a swimming pool before 1927 (Van Everdingen 1972). It is uncertain when this activity ceased but rusting pipes are still found on site and along the pipeline to the Banff Springs Hotel. Within the past 10 years, the origin of the spring, at a cliff face, was excavated by unknown persons allowing water to flow into the small concrete cistern on the surface as well as through a small underground pipe. The concrete cistern was a favourite place to soak and is still listed as such in a recent guide to the hot springs of western Canada (Woodsworth 1999). Soaking is currently an illegal activity at Kidney Spring, and in anticipation of snail re-introduction the area immediately surrounding the Kidney Spring was fenced in November 2001. The level of habitat disturbance by humans observed during regular snail surveys declined significantly ($P<0.05$) following the habitat protection actions (Lepitzki and Pacas 2002, 2003). A v-notch weir pipe insert was also placed into the pipe flowing into the concrete cistern in April 2002, when the spring was dry, to permit more accurate measurement of flow rate (Lepitzki *et al.* 2002a; Hayashi 2004; Schmidt 2005).

The Middle Springs may be the least developed of the Sulphur Mountain thermal springs and are largely in their natural state (Van Everdingen 1972) although they too have been impacted. A commonly held belief suggests that water from the Middle Springs served Dr. Brett's Sanatorium (built between 1886 and 1888) on the site of the present day Park Administration Building (Van Everdingen 1972). According to Elworthy (1926), the Middle Springs were still in their natural state as of August 1923. Marsh (1974) suggests that water used in the Sanatorium and Dr. Brett's *Lithia Water* was more likely drawn from below Middle Springs. Water from Middle Springs was impounded and piped into the fish hatchery in the early 1940s (Marsh 1974). Although the impoundment and scheme was soon abandoned, the stream course and volume did not return to their previous states (Marsh 1974). At one time, water from Middle Springs was also piped to the C&BNHS (Parks Canada 1958). Remnants of pipes and pieces of concrete are found scattered in the Middle Springs area, mostly near the spring origins.

The entire Middle Springs area was designated an Environmentally Sensitive Site (ESS) in 1988 (Environment Canada 1988) and is presently within the Sulphur Mountain wildlife corridor (Parks Canada 1997). The ESS designation recognized that "the upper and lower springs remain the only hot springs on Sulphur Mountain left relatively undisturbed; the warm mineral waters created habitat for rare plants and invertebrates; and that the Parks Service would move to acquire the Middle Springs property and revert it to a natural state" (Environment Canada 1988).

The Middle Springs area in the vicinity of the Upper Middle Spring caves was closed to the public in the summer of 1995 as a result of human fecal pollution (Pacas *et al.* 1996). In June 1997, the Middle Springs area was closed by a Park Superintendent's order "to protect the threatened Banff Springs Snail from disturbance by humans". Even though public access to the Sulphur Mountain wildlife corridor was restricted beginning in November 1997, illegal human use of the thermal springs continued. As at Kidney Spring, the level of human disturbance did not decline significantly until additional measures were implemented early in 2002, in anticipation of snail re-introductions (Lepitzki and Pacas 2001, 2002, 2003). V-notch weirs also were installed in the outflow streams of both Upper and Lower Middle Springs in July 2002.

The most famous thermal spring complex in BNP is the C&BNHS whose development history began with the "discovery" of the Cave in 1883 (Parks Canada 1998). This, the "birthplace of Canada's national parks" system (Parks Canada 1998), has been developed (Van Everdingen 1972) and re-developed:

> "The natural conditions in the area have been modified irrevocably by the construction of the existing facilities. Uncontrolled discharge of spring water can no longer be allowed because of the likelihood that this would lead to damage to the facilities. It is thus impossible to return the area to its natural state. All that one can hope is the creation of the quasi-natural conditions that allow capture and full control of the spring discharge" (Van Everdingen and Banner 1982).

More recently, Grasby and Bednarski (2002) lend support to this conclusion stating: "In order to preserve this site, for historic and ecological reasons, the site must be put into an artificial state of suspended animation". The natural evolution of the cave will be collapse (Grasby *et al.* 2003) but will never be allowed to occur due to Commemorative Integrity concerns (see **Habitat Protection/Ownership**).

The last major re-development at the C&BNHS occurred in anticipation of the Parks Canada centennial in 1985. A series of boardwalks leading to thermal spring origins and over outflow streams was constructed; a new rubber, lined impoundment, Billy's Pool, was made at the Lower C&B Spring; and the Basin Pool was reconstructed. Currently, thermal water is completely confined to constructed pools and outflow streams after surfacing. Outflow is controlled by a series of drains, pipes, and valves before flowing into the Cave and Basin marsh, a Zone 1 Special Preservation Area (Parks Canada 1997). Nearly 165,000 people visited the C&BNHS in fiscal year

1998/1999 (Parks Canada unpubl. data) although visitor numbers have recently dropped to around 100,000 (Parks Canada 2006).

Within the past 10 years (Lepitzki *et al.* 2002b; Lepitzki and Pacas 2007), improvements have been made to the quality of habitat at the C&BNHS through enhanced habitat protection. Swimming in the Basin and Cave pools has been stopped; additional signs, new swing gates, and pickets on boardwalk railings have been installed at several sites; electronic surveillance, motion detecting spot lights, and audio alarms have been installed at some other key sites. A Park Superintendent's Restricted Activity Order was implemented in 2002 for all the springs and outflow streams at the C&BNHS and at Kidney Spring. While this order prohibits entry and the handling or disturbing of any organic material and/or aquatic wildlife within the closed areas, full compliance is still lacking (Lepitzki unpubl. data; Parks Canada unpubl. data). As at other springs, a v-notch weir was installed at the Basin outflow stream in November 2005 in an attempt to enhance habitat before the addition of captive-bred snails and to permit a more accurate measurement of water flow (Lepitzki 2005).

The final, apparent, historic site for *P. johnsoni* is the Cool Springs at Third Vermilion Lake (Figure 5). Although the natural course of the cool springs was destroyed by the construction of the Trans Canada Highway in the 1950s (Holroyd and Van Tighem 1983), the warm waters continue to keep an area of Third Lake ice free during the winter. In November 2005, one of the several thermal spring origins dried but resurfaced on the opposite side of Vermilion Lakes road (Figure 5), additional evidence of the dynamic nature of thermal spring ecosystems.

While the causes and timing of the *P. johnsoni* extirpations at Upper Hot, Kidney, Upper Middle, and Gord's Springs since 1926 will never be known, is it tempting to relate them to thermal spring drying. A thermal spring drying event can be considered a short-term loss of habitat or a severe decrease in habitat quality but only if the water flow returns. The probability of snails surviving the drying episode would be dependent on the time of year and duration. All the extirpated subpopulations inhabited thermal springs that have dried since 1996 for periods ranging from one week to over half a year (Figure 10). With the exception of the Upper Hot, none was historically known to have ceased flowing prior to 1996. Because it is unknown exactly where and when snails were historically collected at the Upper Hot and whether they were empty shells or contained live animals, the 1923 drying cannot be definitely shown as the cause of the Upper Hot extirpation. Similarly, whether earlier, unrecorded drying events contributed to other subpopulation extirpations is uncertain. Normal, seasonal flow reductions coupled with water impoundment and piping could also have contributed to extirpations.

Habitat protection/ownership

All habitat for the Banff Springs Snail is located on federal land in Banff National Park, so enough habitat should be protected to ensure long-term survival of the species. However, four of the five natural subpopulations are found within the Cave and Basin National Historic Site, a high visitor-use area, where maintenance of ecological integrity

(EI) (Canadian Heritage 1994) is not the only guiding principle. Ecological integrity is defined as “a condition where the structure and function of an ecosystem are unimpaired by stresses induced by human activity and are likely to persist” (Canadian Heritage 1994). The C&BNHS became a national historic site in 1985 (Parks Canada 1998) and while it is located within BNP and is subject to the *National Parks* and the *Species at Risk* acts and Regulations, it is also managed (Lepitzki and Pacas 2007) to preserve its commemorative integrity (CI) in accordance with the site’s management plan (Parks Canada 2006) and commemorative integrity statement (Parks Canada 1998). Commemorative integrity means protect, present, and manage cultural resources (Lepitzki and Pacas 2007). Within the past 10 years, conflicts have arisen at the C&BNHS in trying to attain both EI and CI. The Recovery Strategy and Action Plan (Lepitzki and Pacas 2007) states that “the juxtaposition of the snail’s thermal spring habitat within BNP and the C&BNHS requires that recovery can only be achieved if both Ecological and Commemorative Integrity are fully integrated.” It also states that “a key challenge” is protecting and restoring snail populations and habitat while maintaining CI at the C&BNHS. This task may become more challenging as a goal of the draft management plan of the C&BNHS is to increase visitation from its current “more than 100,000 people” per year “by 5% over the next three years” (Parks Canada 2006).

The other high visitor-use area that is also historic habitat for *P. johnsoni* is the Upper Hot Spring. While the recent flow stoppages and current facility operation protocols reduce the quality and suitability of this historic snail habitat (see previous section), significant challenges (Lepitzki *et al.* 2002b) still need to be overcome in order to secure the habitat, including a steady supply of thermal spring water at an appropriate temperature and quality, before the snail can be re-introduced. The feasibility of re-introducing the snail at the Upper Hot will continue to be assessed (Lepitzki and Pacas 2007).

Quality of habitat for the snail also has been compromised by development and facility operations at the C&BNHS. Enhancement and restoration of outflow streams at the C&BNHS are identified as recovery actions (Lepitzki and Pacas 2007).

Also identified in the Recovery Strategy and Action Plan (Lepitzki and Pacas 2007) is the development of a response plan to address habitat destruction and thermal spring drying. Discussion for this response plan included potentially allowing extirpation of certain subpopulations before actions are taken (Lepitzki pers. obs.; Parks Canada 2005a). The Recovery Strategy and Action Plan re-emphasizes this concept with the statement that the intent of the response plan “is to maintain a core group of thermal springs in the event of a catastrophic habitat loss that may affect one or more springs simultaneously” (Lepitzki and Pacas 2007).

The other thermal springs inhabited by the snail, including the Kidney and Middle Springs, are located within human exclusion zones where unauthorized human passage is prohibited. Sophisticated electronic surveillance devices ensure that unauthorized entries are detected. Those apprehended can be charged under provisions of both the *National Parks* and *Species at Risk* acts.

BIOLOGY

No primary publications solely on the biology of the Banff Springs Snail exist or have resulted since the research and recovery program began over 10 years ago; however, some biological data were included in the original COSEWIC Status Report (Lepitzki 1997a), the Alberta Status Report (Lepitzki 2002b), the publication on mtDNA sequencing (Remigio *et al.* 2001), and the hydrogeological articles on the springs (Grasby and Lepitzki 2002; Grasby *et al.* 2003). Data on all aspects of the species, including biology, collected up to 2002 were incorporated into the Parks Canada approved Resource Management Plan (RMP) for the recovery of the snail (Lepitzki *et al.* 2002b); more recent data were summarized for the Recovery Strategy and Action Plan (Lepitzki and Pacas 2007). Data up to 2001 are found within annual progress reports to Parks Canada (Lepitzki 1997b, 1998, 2000a, 2002a) and the Endangered Species Recovery Fund (ESRF) (Lepitzki 1999, 2000b, 2001, 2003a,b, 2004). More recent data are included in monthly and yearly data summaries to Parks Canada (Lepitzki unpubl. data) or are still being analyzed and summarized.

Life cycle and reproduction

Pulmonates are usually annual and semelparous (breed only once, then die) (Brown 1991; Dillon 2000). In general, as temperatures increase, snails grow faster, reproduce earlier, and can have multiple generations per year (McMahon 1983). Most likely, *P. johnsoni* is simultaneously hermaphroditic, similar to other members of the Physidae (Clarke 1973; Dillon 2000). In other physids, mating is not reciprocal in that one partner assumes the male role while the other the female with roles often being swapped (Wethington *et al.* 2000). Outcrossing is preferred (Dillon *et al.* 2002). In other species of *Physella*, reproduction is temperature dependent (DeWitt 1955, 1967; Sankurathri and Holmes 1976). It is uncertain if these generalities apply to *P. johnsoni*.

Transparent, crescent-shaped egg capsules have been observed in all thermal springs inhabited by *P. johnsoni* except Lower Middle and have been observed year-round in the Basin Spring pool although not in every month in a single year. Very small snails (length of shell about 1 mm), also have been observed in the Cave on most snail surveys suggesting that reproduction may not be seasonal. The cryptic nature of the egg capsules may contribute to their apparent density dependent abundance as weak although significant ($P<0.05$) regressions were found in both the Cave and Basin pools between snail and egg capsule numbers observed during snail surveys (see **POPULATION SIZES AND TRENDS**).

Egg capsules have always been found at or slightly above the water's surface, attached to substrates (concrete pool wall, wooden post, floating microbial mat, deciduous leaves, sticks, other living snail shells) suggesting that atmospheric oxygen is required for development. In flow-through aquaria (39.7 litre, 10 U.S. gallon) containing Cave Spring water, egg capsules were, on average, 2.3 mm wide by 5.2 mm long (S.E.M. ± 0.03 and ± 0.05, range 1-4 and 3-8, sample size 280 and 282, respectively) and on average contained 12.3 ± 0.2 eggs per capsule (range 2-23, sample size 262).

In contrast to thermal springs, egg capsules were found throughout the tanks. This may reflect the higher dissolved oxygen levels. Embryos within the eggs grew fully formed snails with shell lengths from 0.5 mm to 0.8 mm; they hatched within three to 10 days (average 5.9 ± 0.2, sample size 66) after deposition. The capsules initially observed in aquaria were noticeably smaller than those in thermal springs and were produced by snails as small as 3 mm shell length suggesting that adult snails, capable of reproduction, have shell lengths greater than or equal to 3 mm. Snails in tanks reached 3 mm within six weeks and began laying eggs after only nine weeks of age. The discrepancy between the number of eggs deposited in tanks and the absence of large number of newly hatched snails suggests that, at least in tanks and under crowded conditions, few of the eggs hatch or few of the newly hatched snails survive once they hatch. Cannibalism was observed where adult snails ate embryos within egg capsules but it was uncertain if the cannibalism was overt or accidental. The lifespan of individual snails is unknown but adult snails have lived for an additional 10 to 11 months once placed in aquaria. The rapidity with which snail populations can increase is shown in **POPULATION SIZES AND TRENDS**.

Predation, parasites, and competition

There are no direct observations of predation of this species by other animals, although waterfowl and other birds are suspected to be the main natural predators.

The potential effects of disease and parasites on mortality of *P. johnsoni* are unknown as no snails have been examined for parasites. Physids are known intermediate hosts for a variety of gastrointestinal flatworms whose definitive hosts (habitat of the adult parasite) are vertebrates such as waterfowl (Olsen 1974).

P. johnsoni presumably grazes on plant material or *aufwuchs* (mixed algal, fungal, and bacterial slime communities growing on hard surfaces, McMahon 1983) like other physids (DeWitt 1955; Clampitt 1970; Brown 1991). The snails have been observed to ingest white-filamentous bacteria. Londry (2005a, b), using stable carbon and nitrogen isotopes, suggested that a white, *Thiothrix*-like organism is the dominant microbial food source for the snail although they also consume cyanobacteria. *Thiothrix* is a sulphide-oxidizing, filamentous bacterium. Soldier fly (Stratiomyidae) larvae, commonly found in the thermal springs on Sulphur Mountain (Lepitzki and Lepitzki 2003), consume a diet (Pennak 1978; Clifford 1991) similar to the snail. Londry (2005a, b) found the larvae ate a mixed diet of *Thiothrix* spp. and cyanobacteria in Banff's thermal springs. Competition for food with soldier fly larvae may be occurring. Typically, the larvae appear to reach their maximum size in late-winter early-spring, as snail populations begin their annual decline (see **POPULATION SIZES AND TRENDS**).

The population effects of these potential natural mortality factors are unknown but may contribute to springtime declines in snail numbers (see **POPULATION SIZES AND TRENDS**). They also could contribute to subpopulation extirpation especially if they occurred during extreme population lows. One of the many actions in the Recovery Strategy and Action Plan (Lepitzki and Pacas 2007) is to produce a response plan that could reduce predation and competition pressures when snail populations are at their lowest.

Physiology

Based on the microdistribution of the snail in the thermal springs, some inferences can be made on the physiological tolerance, or at least preference, of the species. *Physella johnsoni* prefers the upper reaches of the thermal springs that, in comparison to downstream areas (occupied by fewer snails), are significantly (P<0.05) warmer and have higher levels of sulphide but lower pH and dissolved oxygen. However, an anomaly is found at the Cave Spring where snails are also thriving in areas wetted by slow flowing and dripping thermal spring water which is typically between 20°C and 26°C, cooler than that found in the Cave Spring pool (range 27°C to 33°C). Perhaps this anomaly and typically coolest (Figure 6) of the springs currently occupied by *P. johnsoni* helps explain the slight genetic difference of snails in the Cave Spring (see **Genetic description**).

Preliminary experiments in flow-through aquaria containing Cave Spring water examined the snail's thermal preference. After each aquarium was delineated into 27 volumetric cells by dividing each tank face into nine quadrants, an immersion heater was placed into the corner of one of three aquaria. The immersion heater increased water temperature with significant (P<0.05) differences observed among cells only in the tank with the heater (temperature in the cells ranged from 32.5°C to 34.4°C in the tank with the heater and 31.1°C to 31.5°C in the tanks without the heater). This temperature differential did not result in changes in snail microdistribution. No significant differences were observed among cells in any of the other water parameters measured (pH, dissolved oxygen, conductivity) either in the tank containing the heater or the other tanks.

The ability of the species to survive desiccation has not been experimentally tested; however, behaviour in the field has been observed. In general, it appears that snails are able to cope with gradual decreases or increases in water levels by following the change in waterline but drastic drops such as 50 cm in less than 15 minutes have stranded and killed many snails. This magnitude of drop has occurred when valves controlling water levels in the Basin and Cave pools require manipulation to prevent flooding of built resources. Egg capsules, because they adhere to the concrete-edged pools, desiccate and/or freeze with dropping water levels or are most likely asphyxiated with rising water levels.

Dispersal/migration

Active dispersal (via the foot) is limited within springs and extremely unlikely among springs. Microdistributional observations of re-introduced snail subpopulations prove that upstream migration through crawling is possible. Most snails moved upstream immediately upon translocation to the Upper Middle Spring; however, it took 17 weeks before snails were observed upstream within the Upper Middle Spring cave (~5.6 m from their point of translocation) and 45 weeks before they were observed completely around the periphery of the cave (~7.8 m from point of translocation). At Kidney Spring, snails were not observed at the cliff face (4.2 m upstream) until 40 weeks after they were translocated into the cistern. Snails could travel upstream at Kidney both through the underground pipe and through the surface stream. Downstream dispersal, also commonly observed, may be active or, more likely, passive via water currents. Snails have been observed to release their grip on substrates and tumble downstream. Because snail numbers typically drop with increasing distance from thermal spring origin, the importance of the downstream outliers to the subpopulation within each spring is uncertain. Lepitzki (2006) concluded that while these downstream areas have appeared to be population “sinks” over the last 10 years of study, they could become “sources” if thermal spring origins moved or were subject to very localized catastrophes whose effects dissipated by the time they reached downstream areas.

Passive dispersal by birds, a recognized mechanism for gastropod transportation (Roscoe 1955; Rees 1965; Malone 1965a, b, 1966; Dundee *et al.* 1967; Boag 1986), has been proposed as a mechanism for colonization of additional thermal springs after the species evolved *in situ* at the Basin and Cave Springs (Remigio *et al.* 2001). Passive dispersal through pipes linking the Middle Springs with the C&BNHS (see **Habitat trends**) could have occurred. At one time, pipes also linked the Upper C&B and Lower C&B Springs to the Basin Spring (Van Everdingen 1972; Van Everdingen and Banner 1982). The current linkage between the origin pools and outflow streams at the C&BNHS are pipes. Water physicochemistry, dye-tracer, and snail linkages have been observed via the pipes over the past 10 years. For example, a week after reopening a blocked drain at the Lower C&B Spring following provisions outlined in an emergency Environmental Assessment (Leeson 2001), an unprecedented but brief increase in snail numbers was observed in the eastern Cave outflow stream. This was most likely due to a pulse of snails being flushed passively through the pipes.

Anthropogenic dispersal of snails among thermal springs was proposed as a possible mechanism to reduce probability of extinction (Tischendorf 2003). Given low levels of natural dispersal among snail subpopulations and their natural lack of genetic heterogeneity (see **Genetic description**), the appropriateness of moving snails from spring to spring is questionable.

Interspecific interactions

The Banff Springs Snail is dependent on thermal spring water and the corresponding microbial community for food and habitat.

Adaptability

Habitat preferences and tolerances of snails and eggs to water level fluctuations and desiccation have been discussed in **Physiology**. Data on the rapidity of annual population increases and success of re-introductions will be shown in **POPULATION SIZES AND TRENDS**. Some responses to changes in habitat were given in **Dispersal/migration**. Limits to tolerance to natural disturbances and normal, natural seasonal fluctuations in water physicochemistry and microbial community were discussed in **Habitat requirements**, as were potential consequences of thermal spring drying in **Habitat trends**.

Mixed results were obtained from captive-breeding experiments in aquaria. Snails eventually died in tanks re-circulating thermal spring water even though up to half the water volume was changed weekly. This prompted a change to flow-through tanks where Cave Spring water was pumped into three tanks and allowed to drain by gravity. Tank populations, initiated with four snails per tank, increased to peaks ranging from 120 to 285 snails without supplemental feeding; however, difficulties in excluding snails continually entering the tanks through the water pump, even through the various filters, complicated results. These tank populations even began cycling, with population declines apparently related to cessations in egg laying. A change in water physicochemistry in the Cave Spring as a result of cleaning a blocked drain following an emergency Environmental Assessment (see **Dispersal/migration**) and a corresponding change in the tank thermal water regime stopped captive-breeding success. Essentially no reproduction occurred in the captive-breeding tanks for 21 months even though supplemental feeding and other actions were tried. Success also did not occur in three newly established tanks suggesting that the cause of no reproduction was not related to age of snail cultures. It is speculated that something as simple as a change in microbial community diversity, where a microbe that secretes a substance detrimental to the snails becomes established or increases in abundance, could have caused the lack of reproduction in the captive-breeding tanks. After a lull of almost two months, the captive-breeding program was re-initiated with six snails per tank and tank populations reached unprecedented levels, ranging from peaks of 1216 to 1256 snails per tank. An increase in the amount of supplemental food appeared to result in an increase in tank carrying capacity but since supplemental feeding was not continually increased, tank populations levelled.

An additional experiment was tried in the tanks. Six snails from the captive-population were added to each of two tanks containing re-circulating municipal tap water, a third tank acted as control with no snails added. The purpose was to see if snails could survive in tap water as an emergency measure in case a thermal spring dried. Snails thrived and reproduced with tank populations peaking at 479 and 773 snails, well below levels observed in the flow-through tanks, even though fish food flakes were added equally to all tanks containing snails. When tap-water snails were returned to flow-through thermal water tanks, they continued to reproduce suggesting that the Banff Springs Snail could be maintained in tap water as an emergency measure. However, significant ($P<0.05$) differences were found between tap-water and flow-through thermal spring water populations: egg capsules in tap-water tanks were smaller, contained fewer eggs, but also hatched sooner than those in thermal spring water. It is also suspected that shell morphology changed but these conclusions await additional shell measurements.

The captive-bred snails were transferred to the Basin outflow stream when the tanks were decommissioned (Lepitzki 2005). Initially, the Basin outflow stream subpopulation reached unprecedented levels. Whether habitat enhancement, in the form of an in-stream weir and the addition of woody debris, will continue to maintain a higher outflow stream carrying capacity is being monitored. Much of the woody debris added both in the Basin outflow stream and as mitigation in the Lower C&B Spring pool for reverting drainage back into the pipes is now underwater and does not provide emergent habitat for the snail.

Another example of the adaptability or response of the snail also was observed in the Basin outflow stream. Once flow was restored to the Basin outflow stream by manipulating a valve in March 1999, the Basin outflow stream subpopulation rebounded from four snails to more typical levels.

POPULATION SIZES AND TRENDS

Search effort

No historic population estimates exist as the few individuals who collected snails up to 1996 (see **DISTRIBUTION**) did not count snails.

The Banff Springs Snail research and recovery program began in January 1996 with a number of objectives, including determining the distribution and abundance of the species. Protocols were designed whereby thermal springs where the snail was historically found (Clench 1926; Clarke 1973, 1977, 1981) were visited systematically and periodically and examined visually for snails. Maps of the thermal springs and outflow streams, drawn with the aid of compass and tape measure, were used to delineate sections or microsites. The microsite divisions were based on local geomorphology at the scale of less than one metre. Visual surveys consist of intensively searching the microsites, using a headlamp where necessary, without disturbing the substrate. A hand tally counter aided the counting. Some microsites have never been examined due to their inaccessibility e.g., areas adjacent to cliff faces, steep water falls, pipes directing water at the C&NHS, and under boardwalks. Since January 1997, the origin pools and outflow streams of springs where the species was not observed in 1996 have not been intensively examined for snails except for the areas where water physicochemistry is measured. From January 1996 through July 2000, the frequency of regular surveys was tri-weekly (once every three weeks); since then the surveys have been quad-weekly (Lepitzki 2000c).

As the same person (D.A.W. Lepitzki) has counted the snails using the same protocol initiated in January 1996, results from surveys should be consistent and comparable. No doubt, some snails are missed during the surveys so population estimates should be considered minima. Repeat counts were done in the Basin Spring pool in September 1996 over five days (Lepitzki 1997b) in order to determine snail count precision (or repeatability). The number of snails counted varied from day-to-day (117, 131, 156, 98, and 123) but averaged 125 ± 9.5 (S.E.M.) (95% CI ± 26.4). Unfortunately, illegal swimming may have confounded results. If an error of ± 10% is added to the snail counts, 86% and 96% of additional, weekly snail counts at the two re-introduced sites (after the initial decline, see next section, Kidney n=28 and Upper Middle n=24, respectively), fell between those made during the regular quad-weekly counts, attesting to the precision of the visual counts.

Abundance, fluctuations, and trends

Results from regular tri-weekly and then quad-weekly snail counts at each thermal spring and at all thermal springs combined from January 1996 through May 2007 are shown in Figure 11. While these numbers are total numbers of snails observed during the visual counts, they can be considered estimates for mature individuals as larger snails are easier to see and reproduction has been observed in snails as small as 3 mm shell length (see **Life cycle and reproduction**).

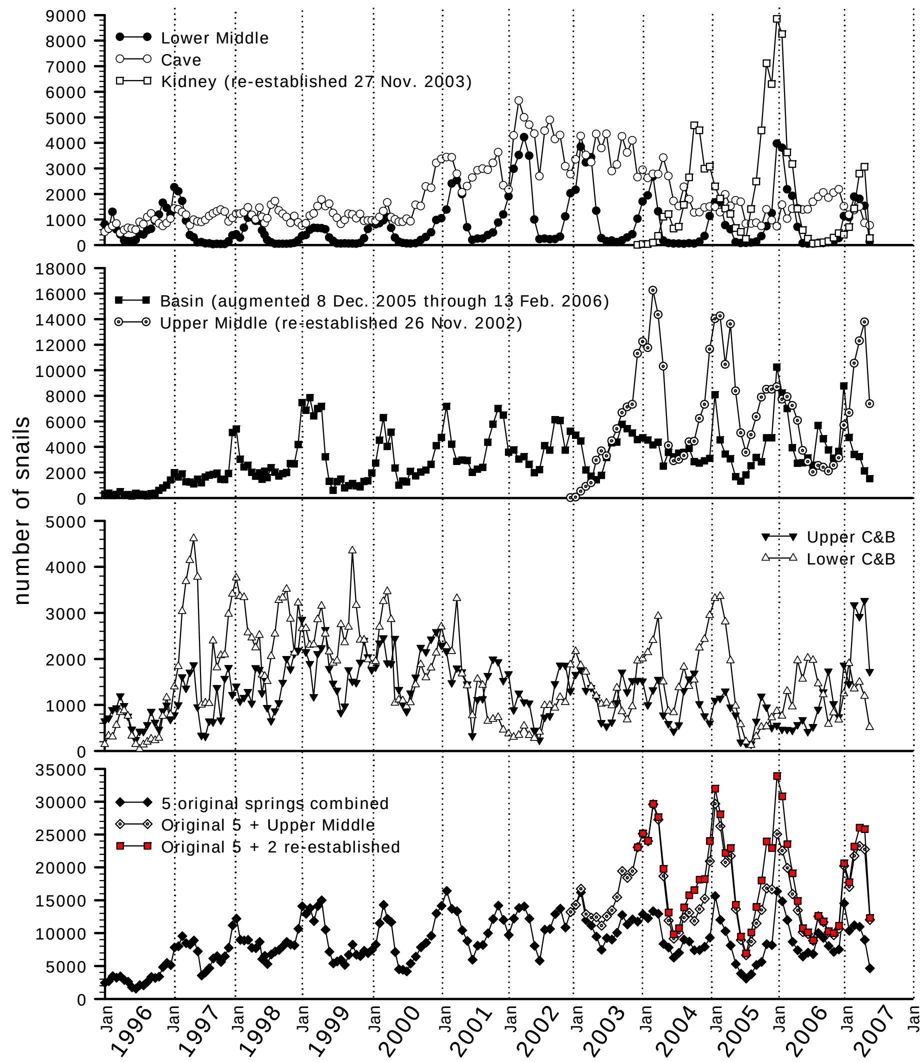

Figure 11. Number of *Physella johnsoni* in each thermal spring and all seven springs combined, January 1996 through May 2007. Re-introduced subpopulations at Upper Middle and Kidney Springs and augmented population at the Basin Spring outflow stream are included. Up until August 2000, population surveys occurred once every three weeks; thereafter they occurred once every four weeks.

Based on direction in the Parks Canada approved Resource Management Plan (Lepitzki *et al.* 2002b) and Environmental Assessment (Lepitzki and Pacas 2001) and subsequent re-evaluations (Lepitzki and Pacas 2002, 2003), snail subpopulations were re-introduced at the Upper Middle and Kidney Springs. Fifty snails were translocated from Lower Middle to the Upper Middle in November 2002; 50 snails (25 from the Upper Middle and 25 from the Lower Middle) were subsequently translocated to Kidney Spring in November 2003. Following initial drops to 16 and eight snails within three and two weeks of the re-introductions, respectively, both subpopulations appear to be sustainable and self-maintaining (Figure 11).

The Basin Spring subpopulation also has been augmented, based on the Parks Canada approved Environmental Assessment (Lepitzki 2005) and SAR (Species at Risk) permit (BA-2005-859) issued to D.A.W. Lepitzki. When the six captive-breeding tanks were decommissioned from 8 December 2005 through 13 February 2006, 7345 snails were added to the upper reaches of the Basin outflow stream. These translocated snails were responsible for the unprecedented increase in the last snail count of 2005 (Figure 11). As previously suggested, the success of this habitat enhancement and population augmentation (see **Adaptability**) continues to be monitored.

Populations of the Banff Springs Snail typically fluctuate by over two orders of magnitude annually with lows occurring during the summer and highs during the late-winter (Figure 11). These seasonal population fluctuations are exactly opposite those of other North American physids. For example, densities of *P. integra* peaked in August-September in Michigan (Clampitt 1974), and in Manitoba densities of *P. gyrina* peaked in June-July (Pip and Stewart 1976). A general limitation of these studies is that year-round sampling is not possible because of winter ice. While Sankurathri and Holmes (1976) also did not sample *P. gyrina* under the ice in their control area, a thermally influenced experimental area of a lake near Edmonton, Alberta was sampled year-round. Even though *P. gyrina* was found to reproduce year-round in the experimental area, peak snail densities still occurred during the summer.

The causes of the annual population fluctuations of *P. johsnoni* are uncertain but may be related to food supply and/or the seasonal dynamics of the thermal spring ecosystems (Lepitzki 2002b).

Including the two re-introduced subpopulations, minimum and maximum population sizes for each spring over the past 10+ years (January 1996 through May 2007) are shown in Table 1. Linear regressions of yearly minima, maxima, and mean for each separate subpopulation (excluding the re-introduced subpopulations) and all subpopulations combined (including those re-introduced) for the years 1996 through 2005 are shown in Figure 12. Due to the magnitude of yearly changes, none of these 10-year regressions were significant (P<0.05) except for the significant increase in yearly maxima at Lower Middle, and significant increases in yearly minima and mean at the Basin (Figure 12). When all five original subpopulations are combined, a significant increase in yearly maxima also was apparent. Highly significant (P≤0.005) increases in yearly minima, maxima, and mean were found only after the re-introduced subpopulations were added to the original five.

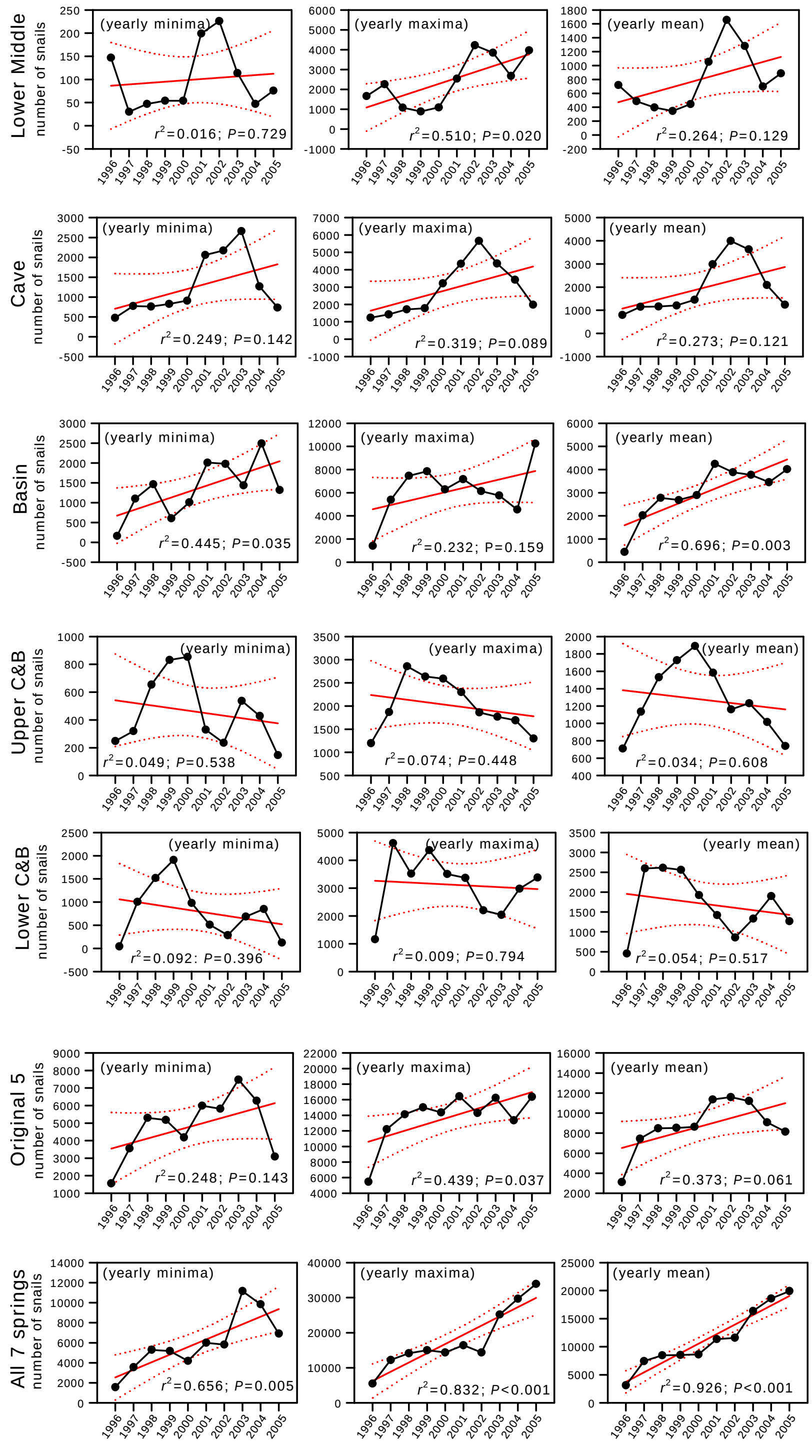

Figure 12. Yearly population minima, maxima, and mean for each subpopulation (except Upper Middle and Kidney), for all five original subpopulations combined, and for all subpopulations including the re-introduced subpopulations at Upper Middle and Kidney, 1996 through 2005. Linear regressions with 95% confidence intervals are plotted as are *r*-square and the *P* for the ANOVA *F*-test.

Tischendorf (2003) modelled snail populations in the five original springs using snail counts from 1996 through 2002 (seven years). Parameters for RAMAS GIS population models were extracted and estimated from the time series analyses. One thousand replicate simulation runs were used to estimate probability of population extirpation and species extinction over a 40 year time horizon. While extirpation probabilities increased over time, most likely due to stochastic events (Tischendorf 2003), there was a low (≤~7.5%) extirpation risk for a time frame of 10 years for each population. Extirpation probabilities still remained around 4% for the Basin and 3% for the Upper C&B subpopulations after 40 years; however, the probability of extirpation was around 21% for the Cave subpopulation, around 29% for the Lower C&B subpopulation, and around 27% for the Lower Middle subpopulation after 40 years (Tischendorf 2003). If all five subpopulations were combined, the probability of extinction was 0% even after 40 years. While these are the "best possible educated 'guess' based on the current knowledge of the biology, life history and habitat requirements for this species", Tischendorf (2003) further and clearly notes there is "substantial uncertainty in the knowledge of demographic data, such as fecundity, survival and dispersal distances" and that these "absolute numbers should be interpreted with caution".

Rescue effect

There is no possibility of a rescue effect from populations elsewhere as the species is endemic to selected thermal springs in Banff National Park.

LIMITING FACTORS AND THREATS

Physella johnsoni is naturally restricted to the upper reaches of a limited number of thermal springs within Banff National Park and consequently its total population is severely fragmented. Individual subpopulations typically undergo natural, annual fluctuations of over two orders of magnitude and few opportunities exist for natural migration among springs except by birds (see **Dispersal/migration**).

Natural and human caused threats to the species and its habitat, whether incidental to facility operations at the Upper Hot and C&BNHS or through other actions by people, have been identified in the Recovery Strategy and Action Plan (Lepitzki and Pacas 2007), are shown in Table 2, and are summarized below. The severity of each threat for each subpopulation has been ranked as H (high), M (medium), or L (low). Criteria for ranking included:

- whether the threat is confirmed and real (there is evidence that the threat has occurred in the past, present, or is anticipated, and results in mortality or decreases in probability of survival), and
- the magnitude of the impact to the snail population.

The severity of the identified threats varies among springs but in general, the higher certainty and severity threats appear in the upper sections of the table.

Table 2. Threats to the Banff Springs Snail and its habitat at each thermal spring in Banff National Park (modified from Lepitzki and Pacas 2007). Whether the threat is N (natural) or caused by humans through FO (facility operations) or other actions (Hu) is indicated. Threats, ranked as H (high), M (medium), L (low) (see text for criteria), unk (unknown), and – (not applicable), are generally arranged vertically from most (top) to least (bottom) severe and certain. The threats indicated for Upper Hot and Gord's Springs are anticipated if the snails are re-introduced at these sites.

Threat	Type	Upper Hot	Kidney	Upper Middle	Lower Middle	Gord's	Cave	Basin	Upper C&B	Lower C&B
Thermal water flow - stoppages	N	H	H	H	H	H	H	H	H	H
Flow – reductions/fluctuations	N	H	H	M	L	M	L	L	L	L
Flow – reductions/fluctuations	FO	H	-	-	-	-	H	H	L	M
Thermal water flow - redirections	N	L	L	L	L	L	L	L	L	L
Thermal water flow - redirections	FO	H	-	-	-	-	H	H	L	M
Limited or low quality habitat	N/FO	M	M	M	M	M	M	M	M	M
Soaking and swimming	Hu	M	M	M	L	L	M	M	M	L
Pop'n lows & genetic inbreeding	N	unk	M	L	M	unk	L	L	M	M
Trampling / local disturbance	Hu	M/L	L	L	L	L	M/L	M/L	M/L	L
Limb-dipping	Hu	M	L	L	L	L	M	M/L	L	L
Stochastic events	N	L	L	L	L	L	L	L	L	L
Others (predation, competition, collecting, twitch-ups)	Hu/N	L	L	L	L	L	L	L	L	L

Thermal water flow stoppages, reductions, and redirections

Thermal water flow stoppages are a localized threat that may affect one or more springs simultaneously and can have severe consequences. Evidence has been presented elsewhere that Sulphur Mountain thermal springs have dried, with an accelerating frequency over the past 10 years. The frequency is expected to increase due to global climate change. While it is uncertain if thermal spring drying led to extirpations since the species was first discovered, flow stoppages were most likely involved. Consequently, the severity of this threat is high for all springs.

Natural seasonal reductions or fluctuations occur in the amount of water flowing in the springs. Mortality of snails has been observed in lower reaches of outflow streams that have dried as a consequence of flow reduction. Because the magnitude of natural flow reduction and fluctuation varies among springs, the severity of the threat also varies with recent history and yearly magnitude of flow variation contributing to the rank.

Flow reductions and fluctuations as a consequence of facility operations occur at the Upper Hot and springs at the C&BNHS. At the Upper Hot, thermal spring water is shunted to the bathing facilities resulting in little suitable habitat for the snail. Van Everdingen (1991) also states that ecological damage to thermal springs occurs through water diversions as well as through returning chlorinated water to outflow streams after use for swimming and bathing. The severity of flow reduction and fluctuation varies at the four springs of the C&BNHS with the highest severity occurring at the springs where all water flow from the thermal spring origin is controlled by pipes and valves. Pipes and valves clogging with microbial growth, debris, and garbage exacerbate natural changes and create unnatural fluctuations in water levels. Water fluctuations have killed snails and eggs at both the Basin and Cave springs.

Water flow redirections occur naturally and as a consequence of facility operations. Because natural flow redirections typically have been observed in lower reaches of outflow streams (e.g., passage of a herd of wapiti *Cervus elaphus* redirected flow of the east Cave outflow stream in April 1998) where snail numbers are lower, the severity of this threat is low. Flow redirections can also occur naturally through tufa mound growth, tree fall, debris deposition, or erosion. Flow redirections due to facility operation occur at the same springs where facility operation flow reductions and fluctuations have been identified and have been ranked identically.

Limited or low quality habitat

Suitable, preferred habitat is naturally limited for this species. Facility operations have further manipulated and changed the habitat. For example, the rapid discharge of water through piping into steep terrain decreases both the quality and quantity of snail habitat in outflow streams.

Soaking and swimming

Soaking and swimming have been documented at most of the thermal springs inhabited by the snail but the extent of this threat varies among springs, primarily as a consequence of what the spring's origin pool looks like. Entering and exiting the pool can crush snails and eggs. Observed disruptions to the floating microbial mat include sinking, stranding, and fragmentation. Significant ($P<0.05$) changes in water clarity, physicochemistry, and snail microdistribution have been observed and measured (Lepitzki 1998, 1999). Dislodged mat can clog pipes and result in facility operation water level fluctuations. Several thousand snails were stranded, froze, and died in February 2005 following illegal swimming in the Basin Spring pool when pipes became clogged with microbial mat and the pool flooded (Lepitzki pers. comm. 2005.). This incident provided snails for isotopic analyses (Londry 2005a, b). While not having yet been examined experimentally, chemicals such as suntan oil, deodorants, and insect repellents could impact snails and their habitat. Others (Kroeger 1988; Lee and Ackerman 1998; Heron 2007) have speculated that the addition of toxic substances (e.g. soap, shampoo, bath and suntan oil, repellents) by bathers may threaten thermal spring flora and fauna. While the level of these illegal activities (prohibited by Park Superintendent closures, except at the Upper Hot) has declined as public knowledge of the snail has increased and habitat protection actions have been implemented, continued vigilance and testing of surveillance devices is required.

Population lows and genetic inbreeding

The natural, annual population low, characteristic of this species, is a natural threat that increases the risk of population extirpation, with those subpopulations that have experienced the most extreme lows during the past 10+ years (Figure 11, Table 1) being the most susceptible (Table 2). A consequence of the seasonal low is genetic inbreeding and a continuous, repeating genetic bottleneck.

Trampling and other local disturbance

Trampling and other local disturbance such as littering, substrate movement or removal, and dam construction have been observed within the past 10 years at all thermal springs historically inhabited by the snail. The frequency and magnitude of this impact varies but is highest at those springs in high visitor-use areas (Table 2). Trampling of fragile riparian habitat and movement or removal of substrates such as the microbial mat, rocks, and floating or emergent woody debris can crush adhering snails or cause them to freeze or desiccated. Littering and the tossing of coins, snow balls, ice chunks, rocks, and logs have been detected (Lepitzki *et al.* 2002b). The addition of copper containing coins may be particularly damaging as copper sulphate was used as a molluscicide (Swales 1935). Even the removal of garbage from snail habitat by well-meaning visitors could kill snails and eggs if the inappropriate substrate is not carefully examined for snails. Boardwalks and barrier fencing at the C&BNHS reduce much of this damage but it still occurs, especially on weekends and during the busy summer tourist season (Lepitzki *et al.* 2002b).

Other threats

The dipping of feet or hands is widespread and occurs regularly, especially at the C&BNHS (Lepitzki 2000d; Thomlinson 2005). Visitor behaviour was observed in 1999 and 2000 (Lepitzki 2000d): 73% of visitors dipped their hands into the Cave Spring pool while significantly (P<0.05) fewer did so at the other springs (12% Basin; 6% Upper C&B; and 8% Lower C&B), possibly because kneeling was required. Thomlinson's (2005) social science study found that limb-dipping continued to occur at the Basin and Cave Springs and suggested that many of the visitors who did so were unaware that the activity was prohibited. Like swimming and soaking, limb-dipping potentially crushes snails and adds toxic substances and is a continuing threat given current and anticipated visitation levels at the C&BNHS. Further actions are proposed to curb this activity and provide opportunities to touch the thermal water without affecting the snail and its habitat (Lepitzki and Pacas 2007).

By definition, stochastic events are random and somewhat unpredictable; however, because of its fragmented habitat and annual population fluctuations this species may be very susceptible to catastrophic population loss though a single, unpredictable chance event. The main reason for increased probability of extirpation was propagation of stochastic events (Tischendorf 2003).

While predation and competition are natural threats, they could result in population extirpation when combined with other threats and especially if they occurred during population lows. Similarly, while unquantified, poaching and shell collecting also are potential threats. Twitch-ups occur along outflow streams when snow-laden branches bend into the water, are colonized by the microbial community and snails, and suddenly twitch-up into the air under warming conditions. Over 40 and 60 of these “quick-frozen” snails have been found in separate incidents along the Lower Middle and Basin outflow streams (Lepitzki 1998).

SPECIAL SIGNIFICANCE OF THE SPECIES

The Banff Springs Snail is endemic to thermal springs in Banff National Park. The Banff Springs Snail was proposed as an indicator for thermal spring ecosystems in the state of the Banff National Park report (Parks Canada 2003) and is an acknowledged indicator of thermal spring ecological integrity (Lepitzki and Pacas 2007). It may also be a keystone species-a species “that makes an unusually strong contribution to community structure or processes” and has “a disproportionate effect on the rest of the community” (Meffe and Carroll 1994). The disappearance of this top grazer could result in the disruption of the thermal spring ecosystem; algae and bacteria may bloom and other organisms potentially dependent on the infusion of snail excrement and shell material may suffer irrevocable harm if the snail is extirpated or becomes extinct. Hebert (1997) notes “not only would its extinction represent the loss of biodiversity, but the ecosystem of thermal springs in Banff might shift due to the loss of an important grazer”.

The importance of species within Canadian National Parks and Parks Canada’s role in preserving biodiversity are acknowledged in the preamble of the *Species at Risk Act* (Statutes of Canada 2002) as helping meet Canada’s commitments to national and international accords on species protection. The snail is identified as a cultural resource at the C&BNHS (Parks Canada 1998) and could be used as a tool to educate visitors about biodiversity and species-at-risk.

The is no known Aboriginal Traditional Knowledge on the Banff Springs Snail, although the C&BNHS was used by Aboriginal people prior to the hotsprings becoming known to the rest of the world after 1883 (Parks Canada 2006).

EXISTING PROTECTION OR OTHER STATUS DESIGNATIONS

The Banff Springs Snail is currently on Schedule 1 of the *Species at Risk Act* (*SARA*) and therefore protected under provisions of *SARA* (Statutes of Canada 2002). It was originally designated Threatened by COSEWIC in April 1997 and then uplisted to Endangered in May 2000 (COSEWIC 2006). Because the only population is found within Banff National Park, *P. johnsoni* is protected under provisions of the *Canadian National Parks Act*. Furthermore, a Banff National Park Superintendent Restricted Activity Order prohibits entry and the handling or disturbing of any organic material and/or aquatic wildlife at the Kidney and C&BNHS springs and outflow streams. The area immediately surrounding Kidney spring has been closed to the public since November 2001. The area enclosing Gord's, Upper Middle, and Lower Middle are within the Sulphur Mountain wildlife corridor (Parks Canada 1997), also closed to the public since 1995. NatureServe (2006) assigns a global rank of G1 and an Alberta provincial rank of S1 primarily from information in the original COSEWIC status report (Lepitzki 1997a) and the Alberta status report (Lepitzki 2002b).

Direction for the species' research and recovery program since January 1996 has been provided by the Parks Canada approved Resource Management Plan (Lepitzki *et al.* 2002b). Future direction is given in the Recovery Strategy and Action Plan (Lepitzki and Pacas 2007).

TECHNICAL SUMMARY

Physella johnsoni
Banff Springs Snail Physe des fontaines de Banff
Range of Occurrence in Canada: Alberta

Demographic Information

Generation time (average age of parents in the population)	<1 yr
Population trend and dynamics Observed percentage of INCREASE in total number of mature individuals over the last 10 years. Results based on linear regression estimates of yearly population minima, maxima, and mean for 1996 through 2005 (Figure 12). Original 5: 1996 max.=10,608; 2005 max.=16,965 All 7: 1996 min.=2,536; 2005 min.=9,358 1996 max.=6,246; 2005 max.=29,908 1996 mean=3,746; 2005 mean=19,058 Original 5 subpopulations combined, minima: no discernible trend in linear regression of yearly minima (P=0.143), maxima: significant increase in linear regression of yearly maxima (P=0.037) and a 60% increase in yearly linear regression estimates of maxima between 1996 and 2005. Original 5 + re-introduced subpopulations, minima: 269% increase, maxima: 379% increase, mean: 409% increase	409% increase
Projected percentage of reduction in total number of mature individuals over the next 10 years.	Not applicable
Inferred percentage reduction in total number of mature individuals over any 10 years period, over a time period including both the past and the future. Decline projected if drying trend of springs continues/increases	Not applicable
Are the causes of the decline clearly reversible?	Not applicable
Are the causes of the decline clearly understood?	Not applicable
Are the causes of the decline clearly ceased?	Not applicable
Observed trend in number of populations	Stable
Are there extreme fluctuations in number of mature individuals? Detailed populations counts occurred once every three weeks from January 1996 through August 2000, and then once every four weeks since then.	Yes
Are there extreme fluctuations in number of populations?	Yes

Number of mature individuals in each population

Population	**N Mature Individuals**
One population with subpopulations	
10+ year minimum and maximum (January 1996 through May 2007), total counts, mostly mature individuals (Table 1)	
Kidney (re-introduced November 2003)	8 – 8,852
Upper Middle (re-introduced November 2002)	16 – 16,247
Lower Middle	30 – 4,221
Cave	474 – 5,657

Basin	162 – 10,242
Upper C&B	147 – 3,268
Lower C&B	43 – 4,619
Grand Total	

Extent and Area Information

Estimated extent of occurrence (km²) In 2006; Historical: 0.345 km^2; 1996: 0.0326 km^2. See p.13 on how this was derived. Historical 1926 excluding the Banff Springs Hotel & Vermilion Cool sites; 1996 includes 5 extant subpopulations; 2006 includes the 5 extant and 2 re-introduced subpopulations.	0.177 km²
Observed trend in extent of occurrence From 1996–2006, 443%; 91% decline historical - 1996. Increase over last 10 years due to re-introducing 2 subpopulations.	Increase
Are there extreme fluctuations in extent of occurrence? Extreme fluctuations possible due to extirpation and anthropogenic re-introductions from extant subpopulations.	Yes
Estimated area of occupancy (km²) AO calculated by Alain Filion, COSEWIC Secretariat, April 2008 Biological area of occupancy, based on the two-dimensional surface area of all microsites (see Table 1): 0.0006 km²	5 km^2 (1×1 km grid)
Observed trend in area of occupancy	Stable
Are there extreme fluctuations in area of occupancy? Extreme fluctuations possible due to extirpation and anthropogenic re-introduced from extant subpopulations.	Yes
Is the total population severely fragmented?	Yes
Number of current locations	3
Trend in number of locations	Increase
Are there extreme fluctuations in number of locations?	No
Observed trend in area, extent and quality of habitat Drying trend of springs removes and affects quality of habitat. Additional protection in the form of Park Superintendent closures, fencing, electronic surveillance, and communication with visitors has improved the overall quality of habitat since 1996.	Decline

Quantitative Analysis

RAMAS GIS population modelling done by Tischendorf (2003) on 7 years of population data (1996 through 2002) for separate subpopulations and all subpopulations combined; subpopulations had not yet been re-introduced at Upper Middle and Kidney and are therefore not included in the analyses. Probability of population extirpation and species extinction estimated from one thousand simulation runs over a time frame of 40 years. Percentage extirpation/extinction probabilities are at the end of the 40 year time frame. Lower Middle: 27% Cave: 21% Basin: 4% Upper C&B: 3% Lower C&B: 29% All 5 combined: 0%	[0% probability of extirpation in 40 years]

Threats (actual or imminent, to populations or habitats)

In order of certainty and severity (highest to lowest) the following threats have been identified (Table 2 and LIMITING FACTORS AND THREATS) and occur naturally (N) or by humans through facility operations (FO) or other actions (Hu): 1. Thermal water flow stoppages (N) 2. Thermal water flow reductions / fluctuations (N and FO) 3. Thermal water flow redirections (N, FO) 4. Limited or low quality habitat (N, FO) 5. Soaking and swimming (Hu) 6. Population lows and genetic inbreeding (N) 7. Trampling and other local disturbances (Hu) 8. Limb-dipping (Hu) 9. Stochastic events (N) 10. Others (predation, competition, collecting, twitch-ups) (Hu, N)

Rescue Effect (immigration from an outside source)

Status of outside population(s)? *Not applicable: Species is endemic to thermal springs in Banff National Park, Alberta.*	
Is immigration known or possible?	Not applicable
Would immigrants be adapted to survive in Canada?	Not applicable
Is there sufficient habitat for immigrants in Canada?	Not applicable
Is rescue from outside populations likely?	No

Current Status

COSEWIC: Threatened (April 1997) COSEWIC: Endangered (May 2000) COSEWIC: Endangered (April 2008) Global Status: G1 Alberta Status: S1

Status and Reasons for Designation

Status: Endangered	**Alpha-numeric code**: B1ac(iv)+2ac(iv)
Reason for Designation: This is a Canadian endemic species with its distribution entirely within the upper reaches of fewer than 5 separate thermal springs locations in Banff National Park, Alberta. These springs comprise a single population, which makes it very susceptible to a catastrophic event. These short-lived animals undergo natural annual fluctuations of over two orders of magnitude. All thermal springs historically or currently occupied by this species have been impacted by human development. These snails are habitat specialists requiring a steady supply of warm thermal spring water containing a high concentration of dissolved minerals and a complex microbial community that provides food and habitat. The species and its habitat are currently protected from disturbance and destruction under *Species at Risk Act* and the *Canada National Parks Act*, but illegal activities such as soaking in thermal waters, which can crush snails and eggs and disturb habitat, are ongoing. The increase in frequency of springs drying due to climate change, which has been observed in the past decade, is believed to be an important threat to this species' survival. However, the species is closely monitored by Parks Canada.	

Applicability of Criteria

Criterion A: (Decline in Total Number of Mature Individuals): Does not apply. There is no current evidence that the population is declining or will decline over the next 10 years.
Criterion B: (Small Distribution Range and Decline or Fluctuation): Meets B1ac(iv)+2ac(iv) 1: EO = 0.177 km² (< 5,000 km²) – Endangered 2: AO = 0.0006 km² (< 500 km²) – Endangered a: Population severely fragmented and found in 3 locations (< or = 5, Endangered), c(iv): Extreme fluctuations of numbers of individuals.
Criterion C: (Small and Declining Number of Mature Individuals): Does not apply. The number of individuals, most mature, varies annually (1,561–33,915) but the population overall has not declined.
Criterion D: (Very Small Population or Restricted Distribution): Meets D2 for Threatened. The species has a very restricted AO (5km²), with 3 locations forming 1 population; it is a habitat specialist requiring geothermally regulated water, a high concentration of dissolved minerals and a complex microbial community. The population is of limited extent and prone to the effects of human activities or stochastic events within a very short time period.
Criterion E: (Quantitative Analysis): A quantitative analysis was done and the probability of extinction in the wild over the next 40 years (based on the 5 original locations) was zero. The probability of extirpation of individual sub-populations was higher: Lower Middle springs 27%, Cave 21%, Basin 4%, Upper Cave and Basin 3%, Lower Cave and Basin 29%.

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The original COSEWIC status report (Lepitzki 1997a) provided a complete list of authorities consulted. To that list can be added the following who have been recently and/or specifically consulted about this updated report: Wayne Nordstrom (Alberta Natural Heritage Information Centre, Edmonton), Dave Poll (Parks Canada Species at Risk coordinator, Western and Northern Service Centre, Calgary, (retired)), Dr. Kent Prior (Parks Canada, Senior Advisor, Critical Habitat, Ottawa), Lindsay Rodger (Parks Canada, Senior Advisor, Recovery, Ottawa), Dr. Amy Wethington (Assistant Professor, Biology, Chowan College, Murfreesboro, North Carolina, U.S.A.), Dr. Rob Dillon Jr. (Associate Professor, Department of Biology, College of Charleston, Charleston, South Carolina, U.S.A.), Dr. Joe Carney (Assistant Professor, Biology, Lakehead University, Thunder Bay, ON and COSEWIC Mollusca SSC member), Dr. Gerry Mackie (Professor Emeritus, Integrative Biology, University of Guelph, Guelph, ON and former co-chair COSEWIC Mollusca SSC) and the several personal communications indicated below.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER

Dr. Dwayne A.W. Lepitzki is an independent biologist who has been on contract with Parks Canada since 1994 working on other aquatic projects (giant liver flukes, amphibians, thermal spring micro and macroinvertebrates) as well as the Banff Springs Snail. He has a B.Sc. (1st class honours) in Zoology from the University of Alberta (1983), an M.A. in Zoology from Southern Illinois University at Carbondale (Cooperative Wildlife Research Laboratory) (1986), and a Ph.D. in Parasitology from McGill University (1993). His Ph.D. dissertation entitled "Epizootiology and transmission of snail-inhabiting metacercariae of the duck digeneans *Cyathocotyle bushiensis* and *Sphaeridiotrema globulus*" involved work on aquatic snail communities in southern Quebec and southeastern Ontario. His undergraduate degree involved work on terrestrial snails and slugs acting as intermediate hosts for ungulate parasites. He has been the Principal Investigator on the Parks Canada research and recovery program for the Banff Springs Snail since 1996, wrote the original COSEWIC status report on the snail in 1997 and the Alberta status report on the snail in 2002, assigned preliminary status ranks to all terrestrial and aquatic gastropods in Alberta in 2001, is an inaugural member of the Banff Springs Snail Recovery Team, was the first author on the Parks Canada approved Resource Management Plan for the Recovery of the Snail (2002), and is the first author on the Recovery Strategy and Action Plan for the snail (2007). He has authored or co-authored over 15 peer reviewed, published papers, over 40 internal reports including Environmental Assessments, and has presented his research findings at over 30 regional, national, and international conferences from Victoria, British Columbia to Liverpool England. In 2005 he was appointed to the Molluscs SSC of COSEWIC.

COLLECTIONS EXAMINED

The original COSEWIC status report (Lepitzki 1997a) provided a complete list of museum authorities who were consulted for specimens and collections. To that list can be added: Gary Rosenberg (Academy of Natural Sciences, Philadelphia, PA) and J.B. Burch (University of Michigan).