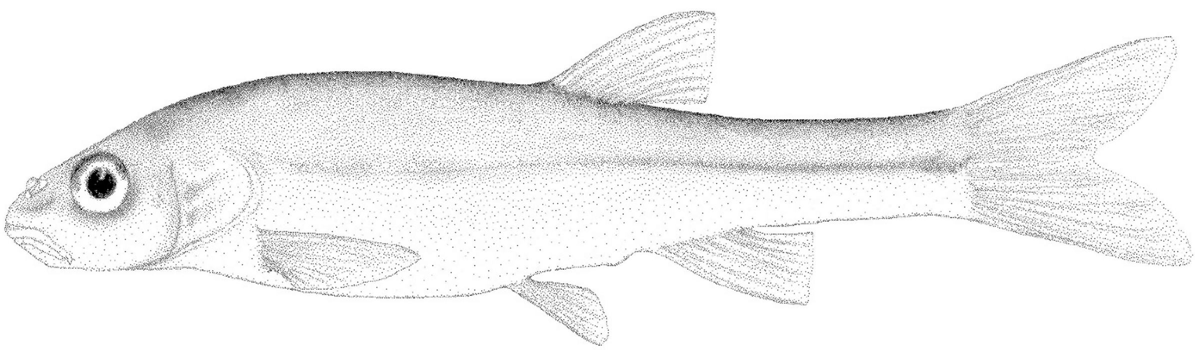
COSEWIC
Assessment and Status Report

on the

Lake Chub
Couesius plumbeus

Liard Hot Springs populations
Atlin Warm Springs populations

in Canada



THREATENED
2018

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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

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Previous report(s):

COSEWIC. 2004. (unpublished report). COSEWIC assessment and status report on the lake chub *Couesius plumbeus* (Northern British Columbia hotsprings populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 27 pp.

Production note:
COSEWIC would like to acknowledge Jacob Schweigert for writing the status report on the Lake Chub, *Couesius plumbeus,* Liard Hot Springs populations and Atlin Warm Springs populations in Canada, prepared under contract with Environment and Climate Change Canada. This report was overseen and edited by Dr. John Post, Co-chair of the COSEWIC Freshwater Fishes Specialist Subcommittee.

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Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur le Méné de lac (*Couesius plumbeus*), populations des sources thermales de la Liard et populations des sources thermales d'Atlin, au Canada.

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COSEWIC
Assessment Summary

Assessment Summary – November 2018

Common name
Lake Chub - Liard Hot Springs populations

Scientific name
Couesius plumbeus

Status
Threatened

Reason for designation
This population of small fish occupies unique thermal spring environments in British Columbia. It has evolved several unique physiological and life history traits that permit persistence in these extreme environments. The small area of habitat in this hot spring complex and risks posed by human activities, including the introduction of exotic species, could result in extinction in a short period of time.

Occurrence
British Columbia

Status history
The species was considered a single population unit (Northern British Columbia Hotsprings populations) in November 2004 and placed in the Data Deficient category. When the species was split into separate units in November 2018, the "Liard Hot Springs populations" unit was designated Threatened.

Assessment Summary – November 2018

Common name
Lake Chub - Atlin Warm Springs populations

Scientific name
Couesius plumbeus

Status
Threatened

Reason for designation
This population of small fish occupies unique thermal spring environments in British Columbia. It has evolved several unique physiological and life history traits that enable it to persist in these extreme environments. The small area of habitat in this warm spring complex, and risks posed by human activities and the introduction of invasive species, could result in extinction in a short period of time.

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Status history
The species was considered a single population unit (Northern British Columbia Hotsprings populations) in November 2004 and placed in the Data Deficient category. When the species was split into separate units in November 2018, the "Atlin Warm Springs populations" unit was designated Threatened.

COSEWIC
Executive Summary

Lake Chub
Couesius plumbeus

Liard Hot Springs populations
Atlin Warm Springs populations

Wildlife Species Description and Significance

Lake Chub is among the most widely distributed members of the minnow family in North America. Historically, it was considered to include three subspecies but they are now considered a single species. The form inhabiting hot springs is a variant of these groups. Based on genetic evidence for discreteness from other taxa and geographic separation as well as ecological adaptation, two designatable units (DU) of Lake Chub inhabiting hot springs in northern British Columbia are recognized. The Liard Hot Springs DU includes the populations at Liard River Hot Springs and the Atlin Warm Springs DU consists of the Lake Chub populations in the Atlin Warm Springs. Due to their broad distribution, Lake Chub play a key role in the maintenance of ecosystem function as a food item for piscivorous birds and fish. The broad distribution and occurrence in a variety of habitats results in little conservation concern for Lake Chub as a species. However, hot springs populations of Lake Chub in British Columbia represent a significant aspect of the evolutionary legacy of the species.

Distribution

The geographic range of Lake Chub extends from the Mackenzie Delta in the north to Colorado in the south, and from the interior Plateau of British Columbia in the west to Nova Scotia in the east. Lake Chub are considered a cold-water fish species and are common in northern British Columbia. However, the hot springs populations are uniquely restricted to the western Arctic Freshwater Biogeographic zone that includes the Liard Hot Springs and the Yukon Freshwater Biogeographic zone containing the Atlin Warm Springs near Atlin Lake.

Habitat

Lake Chub are found in a wide variety of freshwater habitats ranging from northern rivers and lakes to hot springs. Liard Hot Springs is the second largest hot springs complex in Canada. Unlike most other thermal springs, Liard Hot Springs flow into an intricate system of pools, streams and swamps. The vegetation is diverse and includes 14 plant species not otherwise found at this latitude and an endemic endangered snail, the Hotwater Physa. Liard Hot Springs Lake Chub occupy a wide range of temperatures (from about 15 to 26ºC) but at the high end of the range compared to most populations. The Atlin Warm Springs are located in a grassy meadow. The main pool has an upwelling spring at one end and gravel substrate covered with filamentous algae. Temperatures ranged from 25 to 27°C in the pool where Lake Chub are present but they were more abundant in the warmer outlet stream with inflows from minor vents.

Biology

Cold-water Lake Chub have been reported to reach ages of five years or older. However, the Liard Hot Springs Lake Chub has a shorter life span, seldom beyond age two, making it prone to abundance variation. In typical cold-water environments Lake Chub sex ratios are expected to be equal. However, in the unusual environment of the Liard Hot Springs, the sex ratio was biased toward females. Coincidentally males were also found to have a higher level of infection by the blackspot parasite. Spawning occurs during the months of May through August in cold-water populations, often involving a migration from deep water to shallow in lakes or from lakes into streams beginning after ice breakup. Liard Hot Springs Lake Chub were sexually mature in October similar to cold-water populations and probably spawn in spring. Females are batch spawners and release only a few of their 500 to 2400 eggs per spawning event. Lake Chub are predated by various fishes, birds, small mammals, snakes, turtles, amphibians and predatory insects. Liard Hot Springs Lake Chub appear to be herbivorous, mainly feeding on filamentous algae and *Chara sp*. Elsewhere, cold-water populations of Lake Chub favour zooplankton and insects.

Population Sizes and Trends

Estimates of the abundance of the hot springs Lake Chub populations are based mostly on anecdotal visual observations by various researchers. Lake Chub are shy and cryptic, often hiding under cover making visual assessment difficult. The absolute number of Lake Chub in the Liard Hot Springs complex is not known but they are abundant and may number in the thousands. The populations of Lake Chub living in the Atlin Warm Springs has recently been estimated at 1500 to 2200 using mark-recapture techniques. The Atlin Warm Springs has occasionally been excavated to maintain the main pool for bathing but the impact on abundance is unknown.

Threats and Limiting Factors

The introduction of invasive species, particularly centrarchids such as sunfish that overlap with Lake Chub in the littoral zone of lakes, has substantially reduced Lake Chub abundance in some systems. Similar threats apply to the hot springs populations. The introduction of new fish species to either hot springs DU could have a severe impact (e.g., elimination through predation or competition) as occurred with the extinction of the Banff Longnose Dace from the hot springs at Banff National Park, Banff, Alberta. Lake Chub prefer clean, clear water and any activities that remove water, increase turbidity, or introduce pollutants would adversely affect Lake Chub populations. Liard Hot Springs

Provincial Park is the busiest park in northern BC. Due to heavy use of the park, and the isolation and restricted size of the Lake Chubs' unique thermal environment, recreational human use poses an ongoing threat as bathers are not monitored and may introduce toxins (sunscreen, soap, shampoo) into the water. No development is planned within the park but additional private campgrounds will continue to increase recreation demands on the hot springs. Atlin Warm Springs are regularly accessed for bathing and may be impacted by toxins as well. The main pool has occasionally been excavated to maintain water quality for bathing resulting in temporary reduction of water temperature. Similar ongoing maintenance excavations will continue to threaten the thermal regime. Drilling associated with oil and gas exploration could also threaten the thermal regime of the hot springs and impact the viability of these populations.

Limiting Factors

The total available hot springs habitat is a limiting factor determining overall population abundance. Another limiting factor is the need for continuing stability of water flow and the thermal environment. Changes in hot springs temperature and flow rate have been reported in other areas following earthquake activity. Similar changes in the local environment for Lake Chub populations in either DU could have detrimental impacts on their abundance and viability. Parasitic infection of adult males with the black spot parasite in the Liard Hot Springs appears to be increasing their mortality and skewing the sex ratio in favour of females but it is non-lethal in cold-water populations. If parasitic infestation is responsible for increased mortality of adult male fish in hot springs then the population may be limited by the extent of the parasitism.

Protection, Status and Ranks

The Liard Hot Springs thermal complex is contained within Liard River Hot Springs Provincial Park. The park and the hot springs contained within the park are protected by the *Park Act* of BC that sets management guidelines and restricts resource extraction within Provincial Parks. The Atlin Warm Springs are located on private property and are not similarly protected. NatureServe gives Hot Springs Lake Chub populations a conservation status of G5T2, globally secure but imperilled implying that the hot springs populations are threatened whereas the species as a whole is healthy. The provincial listing by the BC Conservation Data Centre in 2011 is S2 or imperilled and they are red listed. NatureServe assigned the non-Hot Springs Lake Chub a global status rank of secure (G5) and national status ranks of secure (N5) for Canada and the United States.

TECHNICAL SUMMARY

Couesius plumbeus

Lake Chub (Liard Hot Springs populations)

Méné de lac (Populations des sources thermales de la Liard)

Range of occurrence in Canada (province/territory/ocean): British Columbia (Liard and Deer River Hot Springs in the upper Liard River)

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	~1 yr
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. N/A b. N/A c. N/A
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	Set to 12 km² as it is less than the estimated IAO
Index of area of occupancy (IAO) (Always report 2x2 grid value).	12 km²
Is the population “severely fragmented” i.e., is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	No

Number of "locations"* (use plausible range to reflect uncertainty if appropriate)	1
Is there an [observed, inferred, or projected] decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	No
Is there an [observed, inferred, or projected] decline in number of subpopulations?	No
Is there an [observed, inferred, or projected] decline in number of "locations"*?	No
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Inferred decline in habitat quality from increasing human use
Are there extreme fluctuations in number of subpopulations?	No
Are there extreme fluctuations in number of "locations"∗?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	**N Mature Individuals**
Liard Hot Spring	A few thousand, but unlikely >10,000
Total	A few thousand, but unlikely >10,000

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

Threats (direct, from highest impact to least, as per IUCN Threats Calculator)

Was a threats calculator completed for this species? Yes

i. Invasive Species
ii. Water Pollution

What additional limiting factors are relevant?
Maintaining stable temperature and flow of the hot springs

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	No applicable populations
Is immigration known or possible?	Not possible

* See Definitions and Abbreviations on COSEWIC web site and IUCN (Feb 2014) for more information on this term

Would immigrants be adapted to survive in Canada?	N/A
Is there sufficient habitat for immigrants in Canada?	N/A
Are conditions deteriorating in Canada?+	No
Are conditions for the source (i.e., outside) population deteriorating?+	N/A
Is the Canadian population considered to be a sink?+	No
Is rescue from outside populations likely?	No, no rescue population

Data Sensitive Species

Is this a data sensitive species?	No

Status History

The species was considered a single population unit (Northern British Columbia Hotsprings populations) in November 2004 and placed in the Data Deficient category. When the species was split into separate units in November 2018, the "Liard Hot Springs populations" unit was designated Threatened.

Status and Reasons for Designation:

Status: Threatened	**Alpha-numeric codes:** D2
Reasons for designation: This population of small fish occupies unique thermal spring environments in British Columbia. It has evolved several unique physiological and life history traits that permit persistence in these extreme environments. The small area of habitat in this hot spring complex and risks posed by human activities, including the introduction of exotic species, could result in extinction in a short period of time.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Trend rate unknown, no suspected decline.
Criterion B (Small Distribution Range and Decline or Fluctuation): No inferred declines of extreme fluctuations.
Criterion C (Small and Declining Number of Mature Individuals): Unknown number of mature individuals, no continuing decline.
Criterion D (Very Small or Restricted Population): Meets criterion for Threatened, D2. The population has a very restricted index of area of occupancy and one location such that it is prone to the effects of human activities or stochastic events (stocking of invasive species) within a very short time period in an uncertain future, rendering the species capable of becoming Endangered or Extinct in a very short time period.
Criterion E (Quantitative Analysis): Not completed.

+ See Table 3 (Guidelines for modifying status assessment based on rescue effect)

TECHNICAL SUMMARY

Couesius plumbeus

Lake Chub (Atlin Warm Springs populations)

Méné de lac (Populations des sources thermales d'Atlin)

Range of occurrence in Canada (province/territory/ocean): British Columbia (Atlin Warm Springs in the Yukon River system)

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	~1 yr
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline a. clearly reversible and b. understood and c. ceased?	a. N/A b. N/A c. N/A
Are there extreme fluctuations in number of mature individuals?	Unknown

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	Set to 4 km² as it is less than the estimated IAO
Index of area of occupancy (IAO) (Always report 2x2 grid value).	4 km²
Is the population "severely fragmented" i.e., is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	No

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Are there extreme fluctuations in number of subpopulations?	No
Are there extreme fluctuations in number of “locations”*?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	N Mature Individuals
Atlin Warm Spring	1500-2200
Total	1500-2200

Quantitative Analysis

Is the probability of extinction in the wild at least [20% within 20 years or 5 generations, or 10% within 100 years]?	Unknown

Threats (direct, from highest impact to least, as per IUCN Threats Calculator)

Was a threats calculator completed for this species? Yes

i. Invasive Species
ii. Water Pollution

What additional limiting factors are relevant?
Maintaining stable temperature and flow of the warm spring

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	No applicable populations

* See Definitions and Abbreviations on COSEWIC web site and IUCN (Feb 2014) for more information on this term

Is immigration known or possible?	Not possible
Would immigrants be adapted to survive in Canada?	N/A
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Criterion B (Small Distribution Range and Decline or Fluctuation):
No inferred declines of extreme fluctuations.

Criterion C (Small and Declining Number of Mature Individuals):
Unknown number of mature individuals, no continuing decline.

Criterion D (Very Small or Restricted Population):
Meets criterion for Threatened D2. The population has a very restricted index of area of occupancy and a single location such that it is prone to the effects of human activities or stochastic events (stocking of invasive species) within a very short time period in an uncertain future, rendering the species capable of becoming Endangered or Extinct in a very short time period.

Criterion E (Quantitative Analysis):
Not completed.

+ See Table 3 (Guidelines for modifying status assessment based on rescue effect)

PREFACE

The draft report prepared in 2004 was never published and the species was deemed data deficient by COSEWIC. Subsequent research has demonstrated the genetic and physiological uniqueness of these populations in relation to their cold-water conspecifics. The populations inhabiting hot springs have shown significant local adaptation to their unique environment supporting adoption as two distinct designatable units. Because of their remoteness and limited geographic extent, determining population abundance and trend has been problematic and little progress has occurred in that area since the last status report. Crandall and Sadler-Brown (1976) provide a categorization of BC and Yukon hot springs that is adopted here. Thermal springs exceeding a maximum of 35°C are designated hot springs while those ranging between 20 to 35°C are warm springs, hence Liard is labelled a hot spring and Atlin a warm spring.

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
(2018)

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 and Climate Change Canada
Canadian Wildlife Service

Environnement et Changement climatique Canada
Service canadien de la faune

Canada

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

COSEWIC Status Report

on the

Lake Chub
Couesius plumbeus

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Atlin Warm Springs populations

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2018

TABLE OF CONTENTS

WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE 5
Name and Classification 5
Morphological Description 5
Population Spatial Structure and Variability 6
Designatable Units 10
Special Significance 12
DISTRIBUTION 12
Global Range 12
Canadian Range 12
Extent of Occurrence and Area of Occupancy 13
Search Effort 13
HABITAT 14
Habitat Requirements 14
Habitat Trends 15
BIOLOGY 16
Life Cycle and Reproduction 16
Physiology and Adaptability 23
Dispersal and Migration 24
Interspecific Interactions 25
POPULATION SIZES AND TRENDS 26
Sampling Effort and Methods 26
Abundance 26
Fluctuations and Trends 26
Rescue Effect 26
THREATS AND LIMITING FACTORS 27
Threats 27
Limiting Factors 29
PROTECTION, STATUS AND RANKS 30
Legal Protection and Status 30
Non-Legal Status and Ranks 31
Habitat Protection and Ownership 31
ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED 32
Authorities Contacted 32
INFORMATION SOURCES 33
BIOGRAPHICAL SUMMARY OF REPORT WRITER(S) 36

List of Figures

Figure 1. Drawing of a female Lake Chub, *Couesius plumbeus*, sampled from Alpha Swamp at the Liard Hot Springs in September 2000 (Illustrated by Diane McPhail). 6

Figure 2. Phylogenetic relationships among 40 cytochrome *b* mitochondrial DNA haplotypes of Lake Chub (*Couesius plumbeus*, Cp1-40) and selected outgroup taxa as estimated by Maximum-likelihood clustering of sequence divergence estimates (HKY+ G distance). Numbers at branch points represent bootstrap support levels (N = 1,000 pseudoreplicates). Haplotypes accompanied by closed ovals represent fish both from Atlin Warm Springs and Liard Hot Springs. Haplotypes that define the western and eastern lineages are denoted by the thick vertical bars. Rss = Redside Shiner (*Richardsonius balteatus*), Pmc = Peamouth Chub (*Mylocheilus caurinus*) outgroups. (Taken from Taylor *et al.* 2013). 8

Figure 3**.** Approximate location of samples of Lake Chub (*Couesius plumbeus*) in North America. Closed circles represent putative *C. p. greeni*, open circles *C. p. plumbeus*, and open triangles *C. p. dissimilis.* The grey shading represents the geographic distribution of *C. plumbeus*. The thick diagonal dashed line represents the inferred boundary between samples with the western (left of the line) and eastern (right) mitochondrial DNA clades that differed from each other by 2.5% net sequence divergence. The two closed circles with interior white dots represent the Atlin Warm Springs (left) and Liard Hot Springs (right) populations, respectively. Areas within established Pleistocene glacial refugia are shown by the encircled letter symbols: B = Bering, P = Pacific, Mi/Ms = Missouri/Mississippi, and A = Atlantic refugia. (Taken from Taylor *et al.* 2013). 9

Figure 4. Map of British Columbia showing the geographic locations of the Liard and Atlin thermal springs Lake Chub populations in Canada and the two cold-water Lake Chub populations included in a genetic analysis performed by McPhail (2001). 17

Figure 5**.** Decision tree illustrating the identification of 12 putative designatable units (DU) in Lake Chub (*Couesius plumbeus*). The taxon is first subdivided between two major evolutionary (mitochondrial DNA) lineages (western and eastern), then, if applicable, by thermal physiological phenotypes (thermal springs, TS, and non-thermal springs, NTS, populations), then by National Freshwater Biogeographic Zone (NFBZ) (Taken from Taylor *et al.* 2013). 18

Figure 6. Sketch map of the Liard Hot Springs complex (taken from McPhail 2001). .. 19

Figure 7. Estimate of the extent of occurrence and index of area of occupancy for the Liard Hot Springs Lake Chub DU. 20

Figure 8. Modified satellite image of the Atlin Warm Springs (courtesy of A. deBruyn). 21

Figure 9. Estimate of the extent of occurrence and index of area of occupancy for the Atlin Warm Springs Lake Chub DU. 22

List of Appendices

Appendix 1. Threats Assessment for the Lake Chub, Liard Hot Springs populations. .. 37
Appendix 2. Threats Assessment for the Lake Chub, Atlin Warm Spring populations... 41
Appendix 3. Satellite image of the Liard Hot Springs (taken from Google Maps, March 2018). 45
Appendix 4. Photo of habitat showing the Alpha stream at the swamp in the Liard Hot Springs (courtesy G. Wilson)... 46
Appendix 5. Photo of habitat showing the Gamma Pool at the Delta-Epsilon complex in the Liard Hot Springs (courtesy G. Wilson). 47
Appendix 6. Photo of habitat showing the Delta stream at the southern edge of the Delta-Epsilon complex in the Liard Hot Springs (courtesy G. Wilson). 48
Appendix 7. Satellite image of the Atlin Warm Springs (taken from Google Maps, March 2018). Atlin Lake in the upper left of the image. 49
Appendix 8. Photo of the Atlin Warm Springs (downloaded from http:\theroadchoseme.com/atlin-warm-springs, March 2018). 50

WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Class: Actinopterygii

Order: Cypriniformes

Family: Cyprinidae

Scientific Name: *Couesius plumbeus* (Agassiz 1850).

Synonyms: *Hybopsis plumbeus*

Common Name: Lake Chub, Liard Hot Springs populations and Atlin Warm Springs populations

Other Names: Bottlefish, Chub Minnow, Creek Chub, Northern Chub

French Name: Méné de lac

Lake Chub, *Couesius plumbeus*, are in the minnow family (Cyprinidae) and were first described by Agassiz (1850) as *Gobio plumbeus*. Evermann (1893) later described the same species as *Couesius dissimilis. Couesius* is named after Dr. Elliot Coues and *plumbeus* means “lead coloured.” Historically, three subspecies for *Couesius plumbeus* were recognized including *C. p. greeni* in the upper Columbia and Fraser rivers and adjacent Pacific slope rivers, *C. p. dissimilis,* east of the continental divide, the Great Plains in Canada and the United States to southwestern portions of lakes Superior and Michigan, and *C. p. plumbeus,* in northeastern North America, Atlantic slope watersheds. The relationships among these three morphologically defined forms are complex and not well understood. In some regions the subspecies clearly intergrade (Wells 1978) while at other sites two of the forms occur in the same river as two morphologically discrete entities (Hubbs and Lagler 1958). Insufficient understanding of the complex intraspecific relationships among these three forms (Scott and Crossman 1973; Wells 1978) and a general trend in the ichthyological literature away from designating subspecies (McPhail 2001) has resulted in the use of *C. plumbeus* for all three forms. While no additional subspecies within *C. plumbeus* are formally recognized, significant intraspecific phylogeographic and adaptive variation has been characterized in recent years. Of particular note, and the focus of this status assessment, is the occurrence of *C. plumbeus* in geothermal spring complexes in northern British Columbia, an unusual environment for this cold-water species.

Morphological Description

Lake Chub is a medium to large-sized minnow with a slender body and a short head (Figure 1). Total adult length can reach 227 mm but is usually less than 100 mm (McPhail and Lindsey 1970; Scott and Crossman 1973). It has a large terminal mouth extending to near the front margin of the eye, with a small barbell near the end of the upper jaw. The origin of the dorsal fin is slightly behind that of the pelvic fins. Scales are medium in size, cycloid, with about 58 to 65 along the side. Eye size, mouth size, and tail fork depth are all moderate. Colouration is dark brown, olive, or almost black above, becoming leaden silver on the sides, and silvery white below. There is an indistinct dark mid-lateral band on the back half of the body. Breeding males in the central distribution develop distinct red patches at the base of the pectoral fins that are absent in the Pacific forms (McPhail and Lindsey 1970). An examination by Wells (1978) of 104 Lake Chub populations across North America concluded that Liard Hot Springs Lake Chub were morphologically distinct from other populations. However, McPhail (2001) identified shortfalls associated with this assertion and re-examined the distinctiveness question. He compared nearby non-hot springs populations from the Liard watershed with Liard Hot Springs Lake Chub to determine if a common Liard phenotype occurred. He concluded that it was the drainage, not the occurrence in thermal springs, that resulted in the distinct morphology and that there appears to be a common Liard body shape shared among hot springs and cold-water populations.

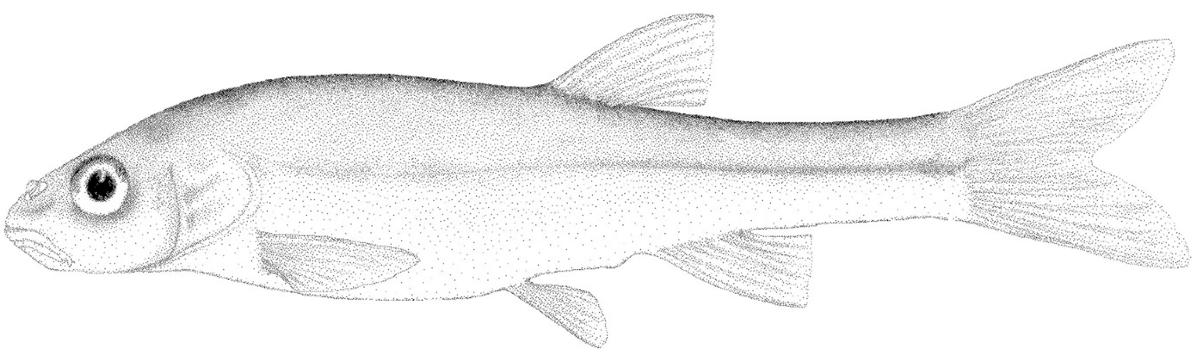

Figure 1. Drawing of a female Lake Chub, *Couesius plumbeus*, sampled from Alpha Swamp at the Liard Hot Springs in September 2000 (Illustrated by Diane McPhail).

Population Spatial Structure and Variability

The extensive geographic range of Lake Chub in North America suggests that it may consist of several distinct phylogeographic lineages because its range overlaps several known Pleistocene glacial refugia (e.g., the Bering, Mississippi, Pacific, and Atlantic refugia) as well as the Rocky and Adirondack mountains in western and eastern North America (Taylor *et al.* 2013). Lake Chub is thought to have achieved this broad distribution via post-glacial dispersal range expansion following the retreat of the Wisconsinan glaciers starting about 10,000 years ago and as part of this process colonized several geothermal spring areas which have since been isolated from the drainage systems in which they occur (McPhail 2007).

To assess the validity of the three original morphologically defined subspecies and to test the hypothesis of the existence of phylogenetic lineages, Taylor *et al*. (2013) examined variation at the mitochondrial DNA cytochrome b gene for 179 individual fish collected from 52 sites across the range of *C. plumbeus* in Canada and the United States with a minimum of 5 to 10 fish from most sites (Figure 3). A total of 40 haplotypes were resolved, with an average of 2.1% uncorrected sequence divergences among each haplotype. Average net divergences between Lake Chub and the cyprinid outgroup taxa Redside Shiner (*Richardsonius balteatus*) and Peamouth Chub (*Mylocheilus caurinus*) were 14.2% and 15.7%, respectively. The monophyly of Lake Chub mtDNA was supported by these data and identified a subdivision into two major groups (Figure 3) differing by a mean 3.8% sequence divergence (2.5% after accounting for variation within groups). One group consisted of all samples located from northwestern Ontario and east, and the other included all samples west of this area (Figures 2 and 3). Haplotypes within the western group differed from each other more (average divergence of 1.7%, N = 126 fish, 31 haplotypes) than the eastern haplotypes (1.0%, N = 53 fish, nine haplotypes). In addition to the major east-west split between haplotype groups, a few sub-groups were resolved (Taylor *et al*. 2013). One sub-group included two fish from the Nahanni River, NWT (86% bootstrap support, Cp35 and Cp36) and another sub-group consisted of fish from western tributaries of Hudson Bay and fish from the South Saskatchewan River system (76% bootstrap support) within the western group (Figure 2, Cp11, Cp20-25). Similarly, a sub-group of two fish from the Lake Superior sample (96% bootstrap support, Cp9 and Cp32) was identified within the eastern group. All sequences from fish sampled from Liard Hot Springs and Atlin Warm Springs belonged to the western group (Figure 2); ten fish, six from Atlin Warm Springs and four from Liard Hot Springs were characterized by the same haplotype (Cp3) which was the most common haplotype (N = 56) in the sample while another nine, six Atlin Warm Springs and three from Liard Hot Springs, were a closely related haplotype (Cp30, ~0.4% divergence from Cp3). One fish from Liard Hot Springs was an additional haplotype (Cp7, 0.2 and 0.6% divergent from Cp3 and Cp30, respectively). Assuming constant population sizes, Taylor *et al.* (2013) report a divergence of the eastern and western groups 2.5 million years ago (lower and upper bounds of the 95% highest posterior density interval of estimates were 0.522 and 6.66 million years ago, respectively). Under an expanding population scenario, the estimated divergence was 3.1 million years ago (lower and upper bounds of the 95% highest posterior density interval of estimates were 0.492 to 8.61 million years ago, respectively). There was some association between major phylogenetic groups and historical subspecies designations (e.g., all *C.p. greeni* occurred within the western lineage while all *C.p. plumbeus* occurred within the eastern lineage). However, there was also a mismatch where *C.p. dissimilis* was characterized almost exclusively by the western clade except for one sample found to be from the eastern clade (Taylor *et al.* 2013).

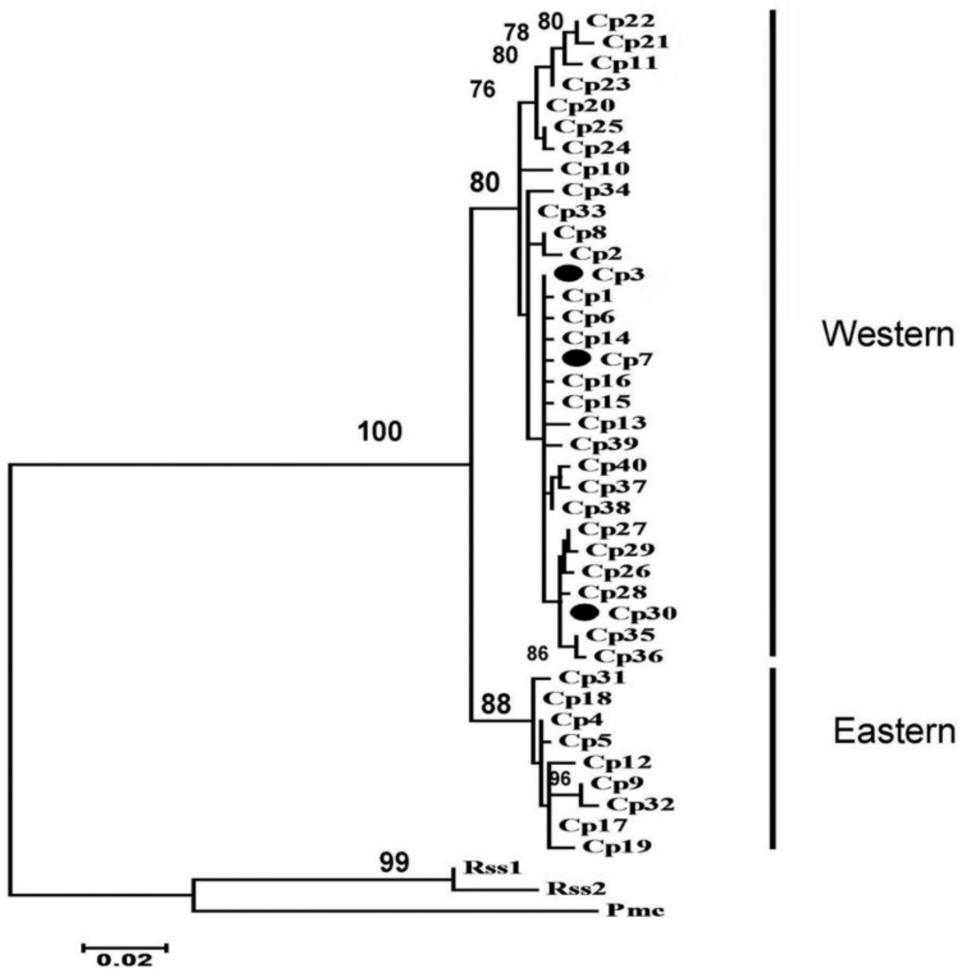

Figure 2. Phylogenetic relationships among 40 cytochrome *b* mitochondrial DNA haplotypes of Lake Chub (*Couesius plumbeus*, Cp1-40) and selected outgroup taxa as estimated by Maximum-likelihood clustering of sequence divergence estimates (HKY+ G distance). Numbers at branch points represent bootstrap support levels (N = 1,000 pseudoreplicates). Haplotypes accompanied by closed ovals represent fish both from Atlin Warm Springs and Liard Hot Springs. Haplotypes that define the western and eastern lineages are denoted by the thick vertical bars. Rss = Redside Shiner (*Richardsonius balteatus*), Pmc = Peamouth Chub (*Mylocheilus caurinus*) outgroups. (Taken from Taylor *et al.* 2013.)

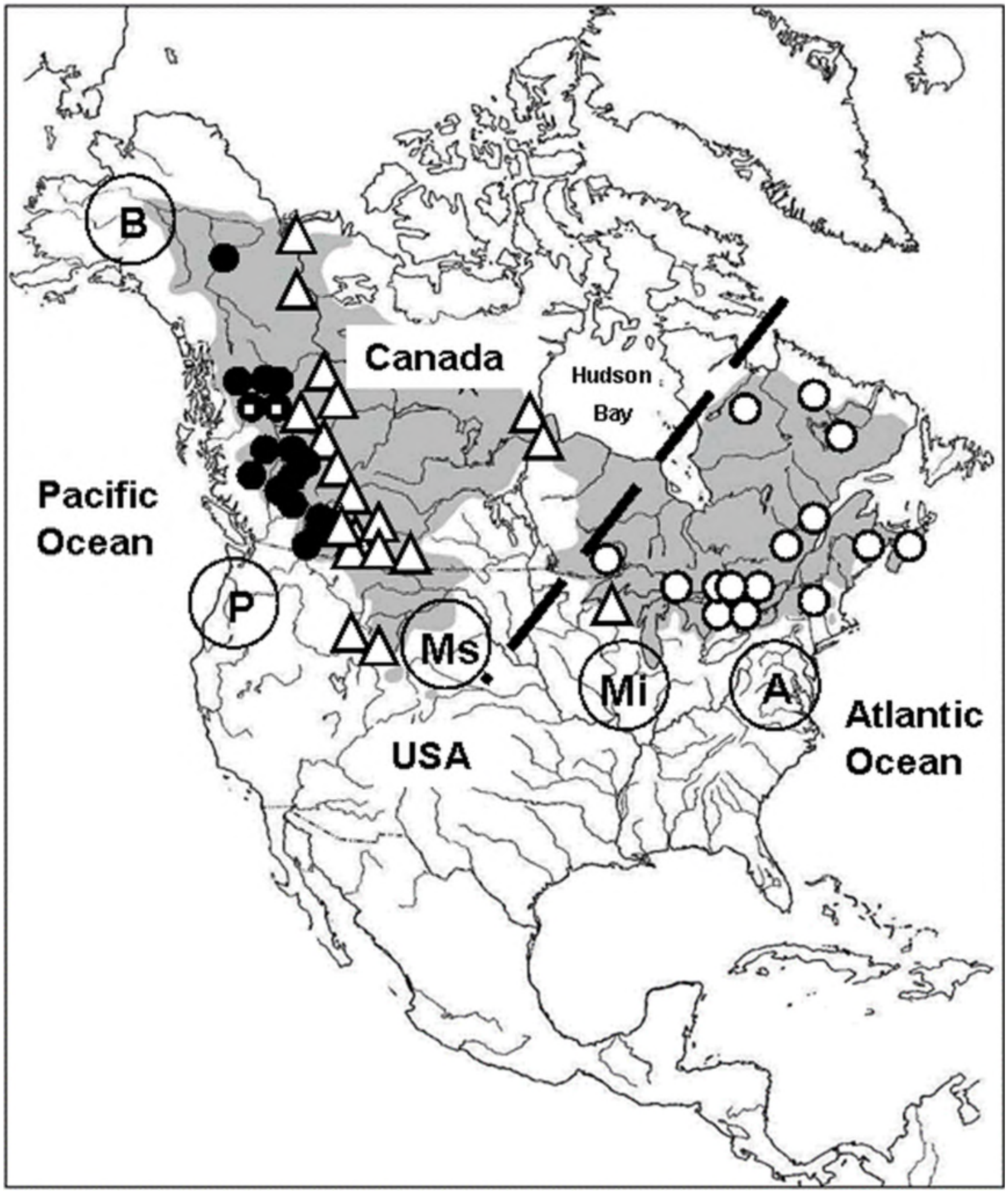

Figure 3**.** Approximate location of samples of Lake Chub (*Couesius plumbeus*) in North America. Closed circles represent putative *C. p. greeni*, open circles *C. p. plumbeus*, and open triangles *C. p. dissimilis.* The grey shading represents the geographic distribution of *C. plumbeus*. The thick diagonal dashed line represents the inferred boundary between samples with the western (left of the line) and eastern (right) mitochondrial DNA clades that differed from each other by 2.5% net sequence divergence. The two closed circles with interior white dots represent the Atlin Warm Springs (left) and Liard Hot Springs (right) populations, respectively. Areas within established Pleistocene glacial refugia are shown by the encircled letter symbols: B = Bering, P = Pacific, Mi/Ms = Missouri/Mississippi, and A = Atlantic refugia. (Taken from Taylor *et al.* 2013.)

Designatable Units

COSEWIC supports the identification of intraspecific designatable units (DUs) for assessment purposes where populations can be demonstrated to be both discrete from other DUs and evolutionarily significant in terms of their contribution to the diversity of the species. The first consideration based on COSEWIC criteria for DU designation is the presence of recognized sub-species or varieties. Although three sub-species of Lake Chub were identified historically based on morphological differences, the genetic basis for this variation is unknown and some geographic areas of morphological intermediacy exist (McPhail 2007; Wells 1978). Further, the phylogenetic data strongly support the existence of two major clades (eastern and western), which only partially align with the putative sub-species based on morphological differentiation (Taylor *et al.* 2013). Thus, historic sub-species classification is not supported by current scientific information and does not warrant DU status. The second consideration is that a DU must not only be discrete from other DUs but also evolutionarily significant relative to other DUs. Taylor *et al.* (2013) conducted an extensive investigation of the phylogenetic relationships for Lake Chub across much of its North American range. Division of the species into two phylogenetic groups was strongly supported by these analyses. The deep divergence (on average ~3.8% sequence divergence) and geographical separation associated with these two clades (Eastern and Western) is a clear indication that these discrete lineages have been separated for a very long time (2.5 M years) and are worthy of separate DU status.

Lake Chub occur in every Canadian province and territory except Prince Edward Island and the island of Newfoundland. Within this broad distribution, Lake Chub undoubtedly inhabit a diversity of habitats; however, they have been observed in only several geothermal springs, a setting highly unusual for a species generally restricted to a cold-water distribution. Such a situation could give rise to unique local adaptations that result in populations that are not ecologically interchangeable with other populations. It seems probable that each of these hot springs Lake Chub populations was independently derived from cold-water ancestors. However, their shared thermal environment may have selected for similar adaptive genetic changes in physiology, ecology, life history, and morphology. Reproductive isolation from cold-water Lake Chub populations, a prerequisite for the evolution and maintenance of such genetic adaptations, is provided by geographic barriers to fish migration. The outflow from the Liard Hot Springs is contained entirely within the adjacent swamps and flooded forest (McPhail 2001; BC Parks 2003). The portion of the upper Liard River adjacent to the Liard Hot Springs is also not known to contain Lake Chub (FISS 2004; McPhail, pers. comm. to Taylor and Stamford, 2003). Lake Chub also occur in watersheds adjacent to Atlin Warm Springs, in Atlin Lake (FISS 2004). There is also currently a continuous stream that connects the Warm Springs complex to the lake (flowing under the Warm Bay road through a culvert) although no Lake Chub have been observed so far downstream from the Hot Springs (A. deBruyn, pers. comm. 2018). It had previously been observed that the outlet stream gradually dissipated until it disappeared as it neared Atlin Lake, effectively separating the hot spring from the lake (McPhail, pers. comm. to Taylor and Stamford, May 2003) so it may be ephemeral.

There is no doubt that the thermal springs environment is an unusual ecological setting for this cold-water species; these environments provide much greater thermal stability year-round compared to typical Lake Chub habitats and also maintain higher temperatures on average. Indeed, physiological adaptation in response to these environments is evident for the two populations examined although the genetic basis for these traits is yet to be determined (Taylor *et al.* 2013). Darveau *et al.* (2012) demonstrated using acclimation experiments that temperature tolerance was altered in these thermal spring populations based on the year-round conditions associated with these geothermally modified environments. Lake Chub in Atlin Warm Springs live in a much less variable 25 to 27°C environment than do the more typical cold-water Lake Chub. These fish showed lower thermal tolerance with narrower thermal breadth, and higher values of CT_{min} (Critical Thermal Minimum temperature), as might be predicted where temperatures are fairly constant over time. They also had lower energy metabolism enzyme activities and lower protein content when challenged with lowered water temperatures than Lake Chub from Liard Hot Springs, which live in a seasonally variable habitat with a high maximum temperature (10 to 27°C) or Lake Chub from Green Lake, (a typical lake in the central interior of BC which freezes over in winter). Lake Chub from Liard Hot Springs, in contrast, showed some evidence of increased tolerance with elevated CT_{max} (Critical Thermal Maximum temperature, when fish were acclimated at the lower temperature of 10°C) and increased energy metabolism enzyme activities at low water temperatures compared to Atlin Warm Springs Lake Chub or Lake Chub from typical cold-water environments. In general, thermal physiology variation observed among populations appeared to be associated with thermal variation of the habitat (Darveau *et al.* 2012). In addition, the thermal springs populations are geographically discrete from other cold-water Lake Chub populations owing to their physical separation, and not ecologically interchangeable owing to their physiological adaptation to the unusual thermal regime of the hot springs environment, thus meeting the criteria necessary for DU status.

Finally, the discreteness and significance criteria are met where populations inhabit different aquatic ecoregions (i.e., National Freshwater Biogeographic Zones), which are characterized by different glacial histories, post-glacial distribution patterns and distinct fish and faunal assemblages. Lake Chub occur in all but two of the 14 NFBZs. The thermal springs populations are split between two NFBZs; the Western Arctic (Liard) and the Yukon (Atlin). Partitioning across these major watershed-based NFBZs warrants further DU consideration. In summary, a total of 12 DUs is proposed for Lake Chub in Canada as outlined in Figure 5. Given that most of these DUs exist over a very large area and potentially each contain many populations with little status information, they are not being considered at present.

Therefore, for the purposes of this assessment, two DUs associated with the extremely limited occurrences in thermal springs in Canada are identified: Western Arctic Thermal Springs DU (Liard Hot Springs populations) and the Yukon Thermal Springs DU (Atlin Warm Springs).

Special Significance

Lake Chub is among the most widely distributed minnows in North America. As such it plays a key role in the maintenance of ecosystem function and is an important food item for piscivorous birds and fish, transferring energy throughout the aquatic habitat and adjacent terrestrial ecosystem. Additionally, these thermally adapted populations represent a unique aspect of the species' post-glacial colonization of Canada's freshwater systems. At some point, drainage connections enabled Lake Chub to access these thermal spring environments, but they have since been cut off from other neighbouring populations. Evidence to date suggests that a combination of isolation and exposure to an altered thermal regime has led to local adaptations in both populations examined. Given that other research has demonstrated that Lake Chub are cold-water specialists requiring exposure to low temperatures to ensure normal sperm development, the physiological shifts observed for thermal spring populations is of particular note and considered an irreplaceable component of intra-specific diversity.

DISTRIBUTION

Global Range

Lake Chub are only found in freshwaters of North America and have one of the widest distributions of any endemic minnow (Figure 3). They occur from the Canadian maritime provinces in the east south to the Delaware River in the northern Atlantic slope rivers in the United States, through the Great Lakes region, a single locality in the upper Mississippi River, the Platte and Missouri rivers in the central United States, the Hudson Bay and Mackenzie River drainages in northern central Canada, and extending west to the upper Yukon and upper Columbia rivers and throughout the Peace and Fraser rivers in western North America (Taylor *et al.* 2013). Lake Chub are considered a cold-water species; certainly, they have the most northern distribution of all cyprinids in North America and are the only minnow found in Alaska, Yukon, Nunavut and Ungava (McPhail 2001). Furthermore, most Lake Chub populations live in streams and lakes that experience strong seasonal variation in water temperatures.

Canadian Range

Lake Chub occur in every Canadian province and territory except Prince Edward Island and the island of Newfoundland. Lake Chub are common in northern British Columbia, occurring in all major river systems (Skeena, Nass, Peace, Liard and Yukon rivers). The upper Liard River system contains the Liard Hot Springs populations located along the Alaska Highway in Liard Hot Springs Provincial Park (Figure 4). The second thermal springs Lake Chub population occurs in the Atlin Warm Springs near Atlin Lake in the Yukon River drainage within the Yukon Freshwater Biogeographic Zone.

Extent of Occurrence and Area of Occupancy

The Liard Hot Springs is a complex of springs, pools, swamps, and streams. Lake Chub are associated with the Liard Hot Spring's Alpha and Delta-Epsilon complexes (Figure 6). The Liard Hot Springs complex has no connections to other streams; its outflow is contained entirely within the adjacent swamps and flooded forest (McPhail 2001; BC Parks 2003). The extent of occurrence (set to IAO) and index of area of occupancy are estimated as 12.0 km^2 (Figure 7). Reports of Lake Chub being associated with three other upper Liard Hot Springs at Deer River, Crooked Lake and Portage Brule, remain unconfirmed. It is unclear if the Lake Chub at the Deer River thermal springs are significant and discrete based on lack of information on thermal behaviour and physiology and connectedness with the Deer River (G. Wilson, pers. comm. 2017). McPhail (2001) suggests that Lake Chub occur in Crooked Lake Hot Spring based on a report by Craig and Bruce (1983). Schultz and Company (1976) reported that Lake Chub are common in the Liard River at the confluence of warm water from the Portage Brule Hot Springs but not in the springs themselves.

The Atlin Warm Springs DU is composed of two major sections, one western and one eastern, with their sources separated by a gap of roughly 400 m of forest and the Warm Bay Road. The western portion contains a series of pools that drain sequentially into one another and then drain down a ditched hillside into Warm Bay. The eastern portion contains a pool roughly 10 by 7 m in size and not more than 1 metre in depth. Warm water wells up in this pool and multiple smaller pools across an open meadow and drains through a branching stream over a series of slopes into a low-lying marsh, which in turn drains into Warm Bay. The outflows of these two different regions are separated by roughly 200 m (A. deBruyn, pers. comm. 2018, Figure 8). Lake Chub inhabit both sections of the warm springs. The extent of occurrence (set to IAO) and index of area of occupancy for the Atlin Warm Springs populations are estimated as 4.0 km^2 (Figure 9).

Search Effort

Effort to assess abundance of Lake Chub populations in either hot springs DU has been extremely limited. The only directed search effort at the Liard Hot Springs site occurred in 2000 when McPhail (2001) conducted a visual assessment for the BC Ministry of Environment, Lands, and Parks. In 2015 to 2016, British Columbia government researchers re-visited the Liard Hot Springs photographing the habitat and making visual assessment of the Lake Chub and recording chemical and temperature readings in several of the pools (G. Wilson, pers. comm. 2017). Most recently a mark-recapture abundance study was conducted in the Atlin Warm Springs to determine population size, movement patterns and site fidelity (A. deBruyn, pers. comm. March, 2018).

HABITAT

Habitat Requirements

Lake Chub are found in a wide variety of freshwater habitats ranging from northern rivers and lakes to hot springs. Lake Chub appear to prefer lakes but can also occupy streams, particularly towards the northern extent of their range, existing in both clear and muddy waters (McPhail and Lindsey 1970; Scott and Crossman 1973). However, it is apparent that they prefer clear, cool water with clean cobble or gravel substrate (Bruce and Parsons 1976; Isaak *et al.* 2003). In small lakes in central British Columbia, Lake Chub remain near the bottom regardless of water depth, occupying both the shallow and deepwater areas, except in lakes where the deepwater zone lacks oxygen during the summer (Geen 1955). In other regions, Lake Chub were most common in the shallow water of lakes at the mouths of tributary rivers and were rarely collected in deep water or very far from the river mouth (Stasiak 2006). Lake Chub appears to be the most cold-adapted of the minnows in North America. It apparently requires low winter temperatures (5 to 12ºC) for normal development of sperm with higher temperatures (16 to 21ºC) hastening or terminating spermiation in pre-spawning fish (Ahsan 1966). Lake Chub spawn in both streams and along the shallows in lakes, at water temperatures greater than 10ºC (Richardson 1935; Brown *et al.* 1970). The type of substrate appears unimportant to choice of spawning site or early egg survival (Brown 1969; Brown *et al.* 1970).

The habitat of the two thermal springs DUs differs markedly from the typical cold-water habitat. Liard Hot Springs are the second largest hot springs complex in Canada and an unique ecosystem. Unlike most other thermal springs in Canada, the Liard Hot Springs do not flow into a nearby river or creek, but flow into an intricate system of swamps (Figure 6). The Hot Springs complex's vegetation is unique compared to outlying areas in terms of species composition, the large diversity of species (including 14 species of orchids), luxuriance of growth and timing of blooming (Reid 1978). The Liard Hot Springs are home to 14 plant species not otherwise found at such northern latitudes and an endemic species of snail, the Hotwater Physa (*Physella wrighti*). The Hotwater Physa has been listed as Endangered under SARA. The unique flora and fauna are supported by the thermal influence of the hot springs, producing a minimal 2ºC increase in annual temperature range relative to surrounding areas; the immediate vicinity remains frost free, and the relative humidity may be high (Reid 1978). The ecosystem is highly sensitive to changes in water quality, depth, flow and temperature (BC Ministry of Parks 1990).

The areas occupied by Lake Chub in the Liard Hot Springs complex, Alpha and Delta-Epsilon complexes (Figure 6, Appendix 3 to 6), have unique habitat characteristics in comparison to both cold-water sites and to one another. In the Alpha complex, Lake Chub are found throughout Alpha Swamp, which starts about 150 m downstream of Alpha Pool, and throughout the flooded forest. In the Delta-Epsilon complex Lake Chub inhabit the hot pools (Delta and Epsilon), and connecting streams. Much of the Alpha complex is shallow rivulets and pools with a substrate of calcareous mud and an abundance of *Chara sp*. The pools of the Delta-Epsilon complex were contained by a now-ruptured beaver dam. The bottom was covered in large woody debris encrusted in green sponge and checkered with patches of filamentous algae and dark organic mud (G. Wilson, pers. comm. 2018). Dense mats of *Chara sp.* are found throughout the Delta-Epsilon complex. The water of both areas has near neutral pH (6.8 to 7.7) and conductivities around 1100 µS/cm. During late summer, the range in temperature (depending on distance from warm upwelling areas) was around 14 to 26ºC in Alpha swamp and the flooded forest, and from slightly less than 20ºC up to 34ºC in the Delta-Epsilon pools (McPhail 2001). Temperatures taken in the pools in September 2015 were in the same range (G. Wilson, pers. comm. 2018). McPhail (2001) observed that Lake Chub occupy a wide range of temperatures in both ponds (from about 15 to 26ºC), but they were particularly abundant in waters with temperatures of 18ºC in the Alpha complex (in the rivulets of Alpha Swamp) and at 23 to 25ºC in the Delta-Epsilon complex. Habitat availability seems to decrease greatly in the Liard Hot Springs complex during winter. In late October, McPhail (2001) visited the Alpha complex and observed that the flooded forest and the edges of the swamp were frozen. A large shallow pool with a temperature of 1.4ºC remained near the parking lot and open water with temperature ranging from 7.8 to 12.3ºC existed under the boardwalk. Under the boardwalk, a few Lake Chub were observed in still waters with temperatures of 7.8 to 11.2ºC but most of the Lake Chub seen were concentrated in two rivulets with water temperatures of 11.5ºC and higher.

The Atlin Warm Springs are located in a grassy meadow (Figure 8, Appendix 7 and 8). It consists of two major sections, western and eastern, separated by roughly 400 m of forest and the Warm Bay Road. The western portion contains a series of pools that drain sequentially into one another through private property, then drain down a ditched hillside into Warm Bay, and has been invaded by goldfish (*Carassius auratus*). The eastern portion contains a publicly frequented pool roughly 10 by 7 m and about 1 metre deep. Warm water enters the pool and several smaller pools across an open meadow, draining through a branching stream into a low-lying marsh, then into Warm Bay (A. deBruyn, pers. comm. 2018). The main pool in the eastern section has an upwelling spring at one end and gravel substrate covered with filamentous algae. When McPhail (2001) visited the pool on September 19, 2000, the water was warm (21 to 24°C), the pH was 7.2, and the conductivity was 414 µS/cm. Lake Chub were present in the pool and remarkably abundant in the outlet stream. The outlet stream was a little warmer than the main pool (25°C) due to inflows from minor vents. The outlet stream, which is completely overgrown with Watercress (*Nasturtium officinale*), meanders across the meadow.

Habitat Trends

Available information on trends in habitat is very limited for both DUs. It is probable that human development has had some negative effects on the habitat of Liard Hot Springs Lake Chub (Lyons 1956; Pavlick 1974). The first boardwalk and pool facilities were built by the American Army in 1942. Liard River Hot Springs Provincial Park was created in 1957. The construction of the parking lot in the provincial park is thought to have killed a large number of Lake Chub (perhaps hundreds) but only a relatively small proportion of the total population (B. Coad, pers. comm. to Taylor and Samford, 2004). Periodic beaver activity has altered the flow in the complex from time to time but does not appear to have caused any negative impacts on the habitat. Most of the public access is restricted to the Alpha pool so overall impact on the DU has been minimal. Temperature measurements throughout the hot springs indicate short term stability (Pavlick 1974).

The Atlin Warm Springs have occasionally been excavated to maintain the quality of the main pool for bathing (R. Keim, pers. comm. to Taylor and Samford, May 2004). Although there are reports that the temperature of the springs was lowered by excavation conducted in the late 1980s (R. Keim, pers. comm. to Taylor and Samford, 2004), when the springs were visited in 2000, they were still warm (21 to 25ºC) and intact (McPhail 2001). The water temperature has been stable at about 25ºC since at least the autumn of 2015 (A. deBruyn, pers. comm. 2018).

BIOLOGY

Despite their Canada-wide distribution, the available information on Lake Chub biology is relatively limited. The most comprehensive report is the thesis by Brown (1969) focusing on Saskatchewan populations. In addition, there is an earlier thesis by Geen (1955) specific to central British Columbia lakes but it is difficult to access. Both McPhail and Lindsey (1970) and Scott and Crossman (1973) provide summaries of available biological information for the species. More recently Isaak *et al.* (2003) and Stasiak (2006) provide extensive summaries of information for the northern United States populations. Finally, McPhail (2001) provides biological information specific to the Lake Chub population of the Liard Hot Springs.

Life Cycle and Reproduction

Becker (1983) cited in Stasiak (2006) reports that Wisconsin Lake Chub reached ages of five years and speculated that some were age 7 but scales were difficult to age. The longevity is consistent with other reports including for BC by Geen (1955). However, the Liard Hot Springs Lake Chub appears to have a much shorter life span, seldom beyond age 2 (McPhail 2001) making it more vulnerable to inter-annual variability in recruitment. It is also evident that females live longer than males.

Sex determination in fish is often influenced by incubation temperature (Conover and Kynard 1981). In the typical cold-water environments Lake Chub sex ratios are expected to be nearly equal. However, in the atypical environment of the hot springs this might be different and McPhail (2001) compared the sex ratios among Lake Chub sampled from the Liard Hot Springs, Atlin Warm Springs, and two cold-water Liard populations (Mill and Hutchinson Creek, Figure 4). Sex ratios were equal (1:1) in the two cold-water populations and in Atlin Warm Springs. However, in Liard Hot Springs, sex ratio was biased toward females: 1.6:1 in Alpha Swamp, 3:1 in Epsilon Pool, and 7:1 in Delta Pool. Because the sex ratio of Lake Chub in Atlin Warm Springs was 1:1, McPhail (2001) speculated that thermal environment was probably not the only factor influencing these inter-population differences. Within the Liard Hot Springs complex, skew in sex ratio appeared to be associated with level of infection by the blackspot parasite (*Neascus sp.*).

Alpha swamp, with a 1.6:1 female to male sex ratio had the lowest level of infection, Epsilon Pool with a 3:1 sex ratio had a moderate level of infection, and Delta Pool with a 7:1 sex ratio had the highest level of infection. Rate of black spot infection for Lake Chub sampled from Atlin Warm Springs and the two cold-water populations was much lower than that observed anywhere within the Liard Hot Springs complex. It appears possible that increased infection of males with black spot results in earlier mortality thereby skewing the sex ratio although it is generally believed to be non-lethal in most other cold-water species.

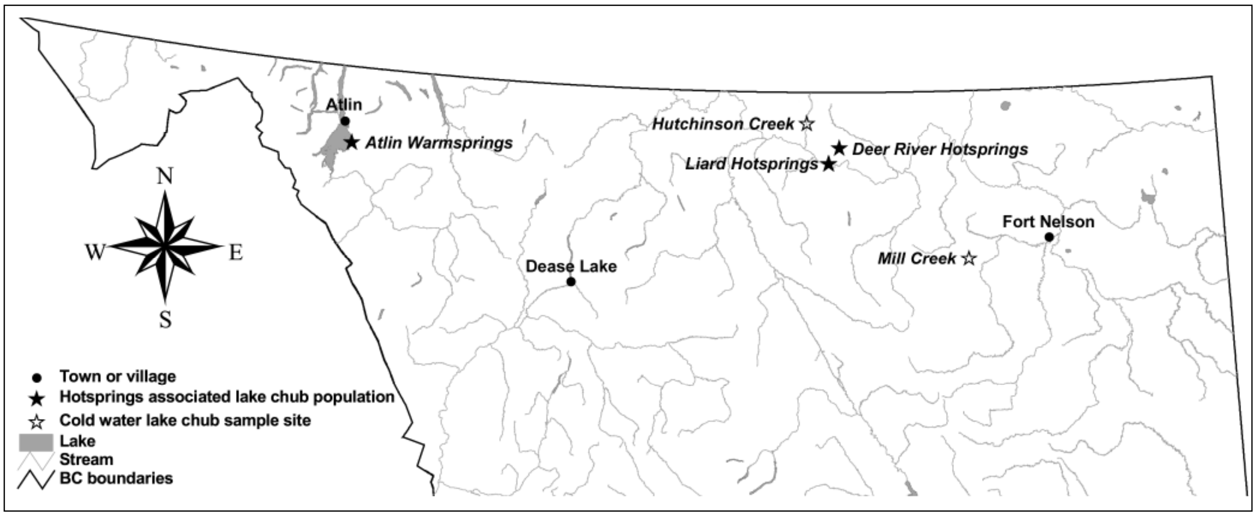

Figure 4. Map of British Columbia showing the geographic locations of the Liard and Atlin thermal springs Lake Chub populations in Canada and the two cold-water Lake Chub populations included in a genetic analysis performed by McPhail (2001).

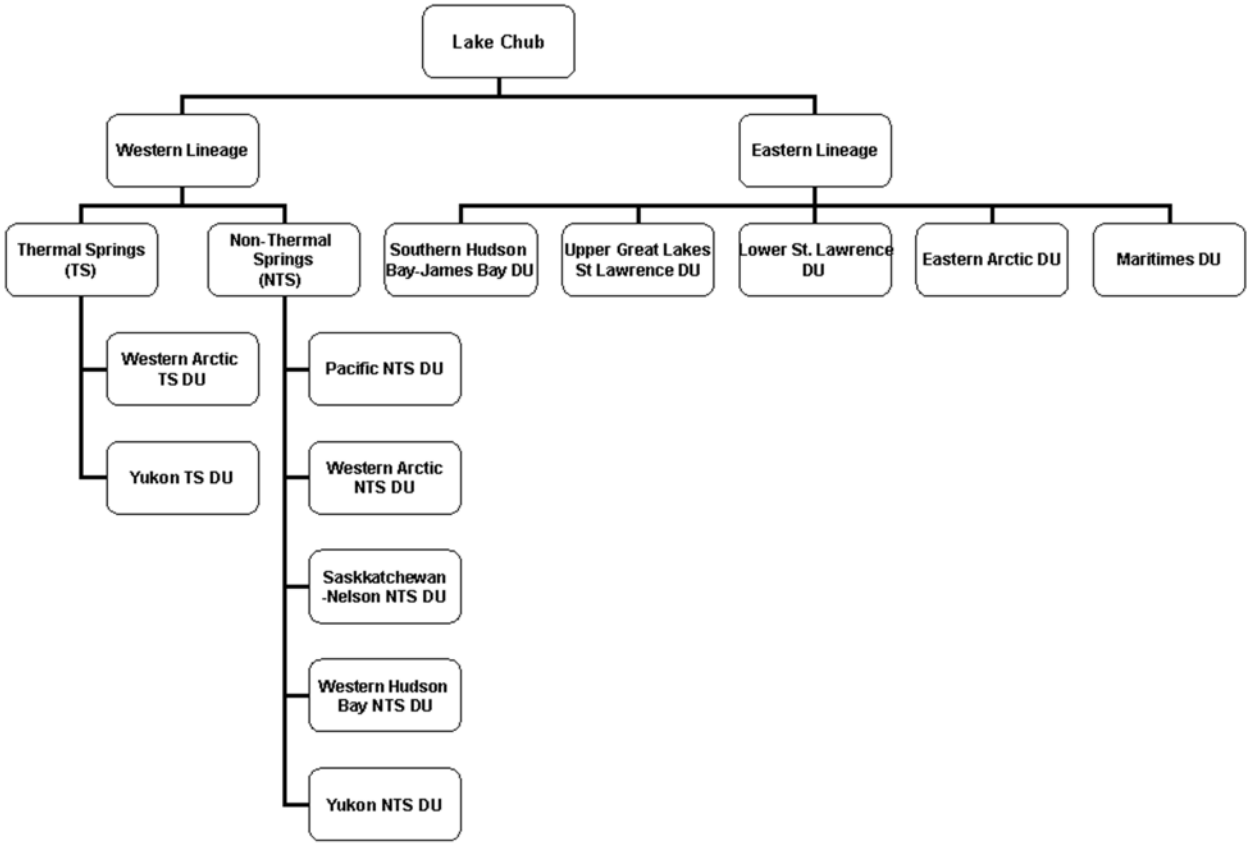

Figure 5**.** Decision tree illustrating the identification of 12 putative designatable units (DU) in Lake Chub (*Couesius plumbeus*). The taxon is first subdivided between two major evolutionary (mitochondrial DNA) lineages (western and eastern), then, if applicable, by thermal physiological phenotypes (thermal springs, TS, and non-thermal springs, NTS, populations), then by National Freshwater Biogeographic Zone (NFBZ) (Taken from Taylor *et al.* 2013.)

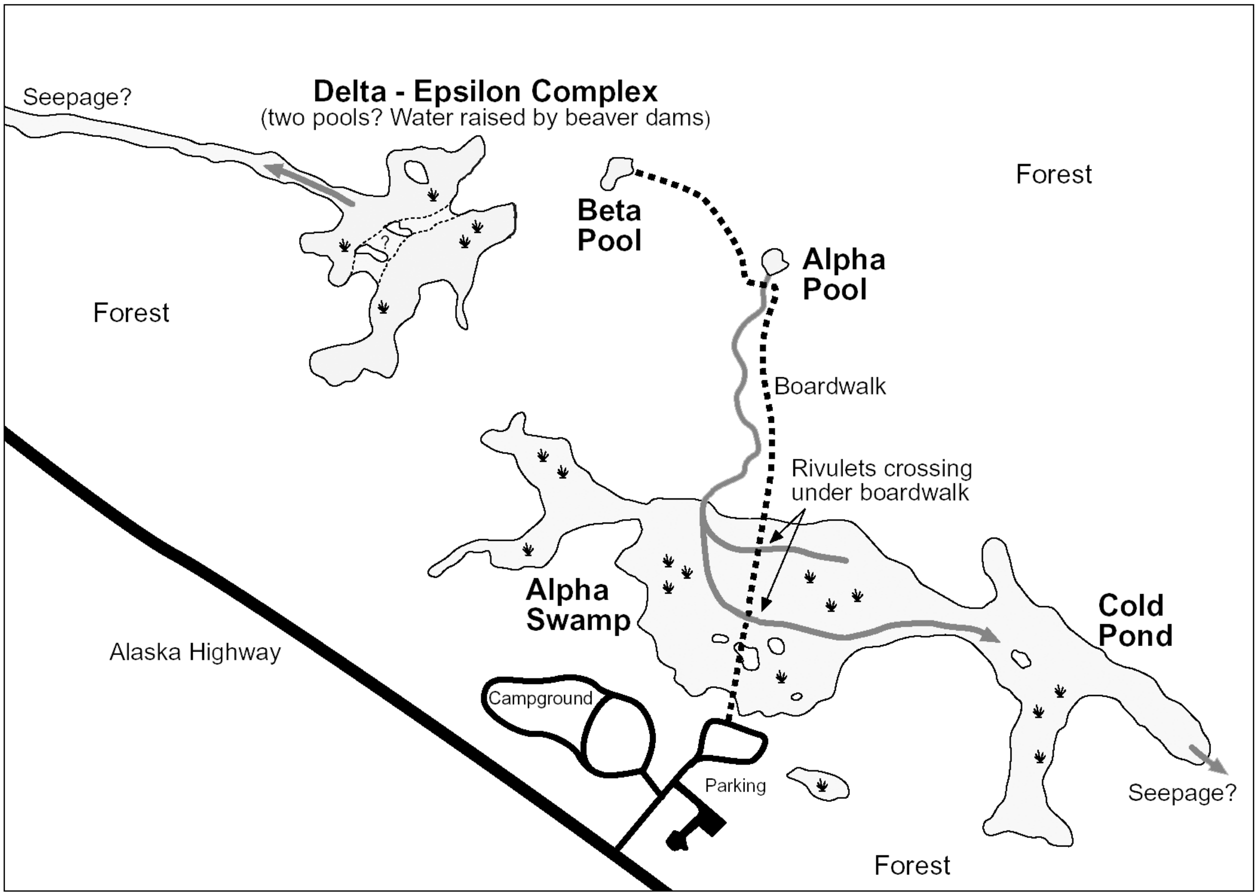

Figure 6. Sketch map of the Liard Hot Springs complex (taken from McPhail 2001).

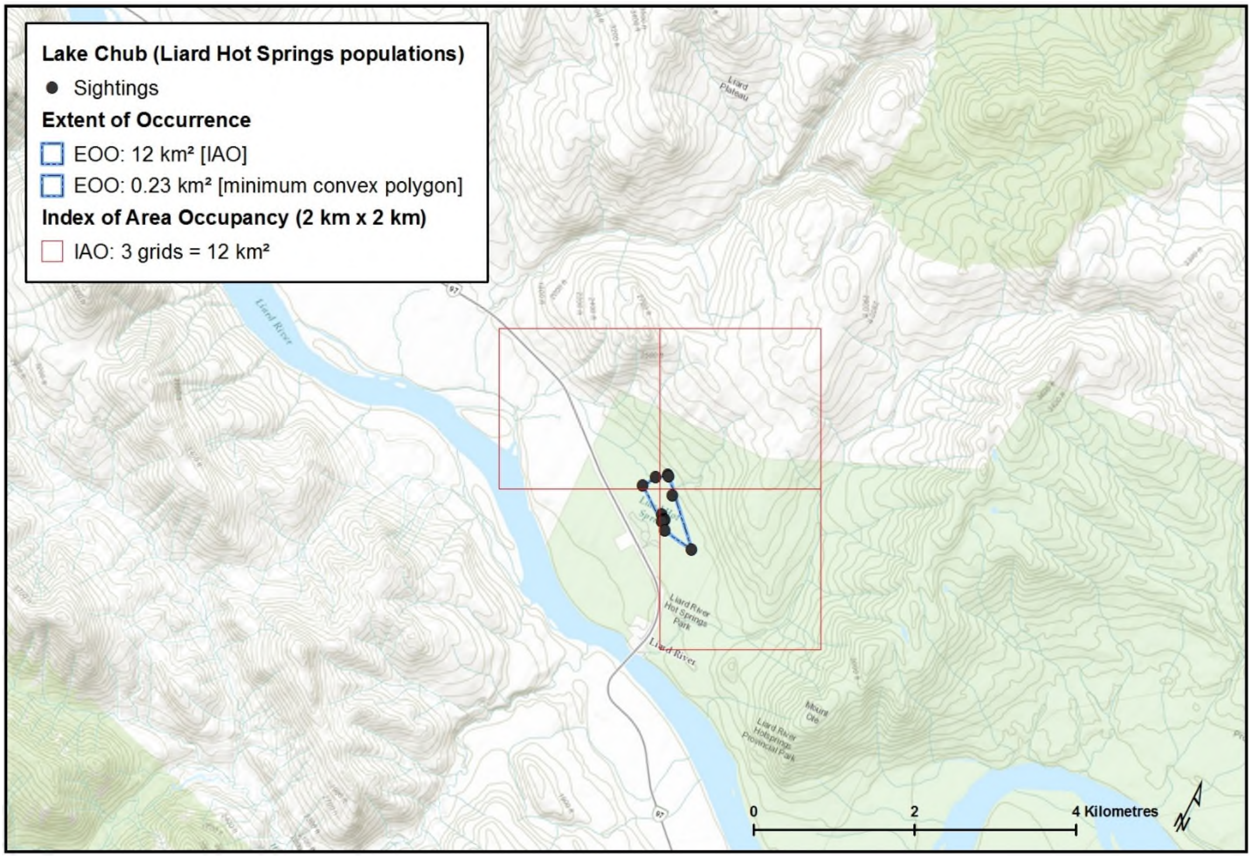

Figure 7. Estimate of the extent of occurrence and index of area of occupancy for the Liard Hot Springs Lake Chub DU.

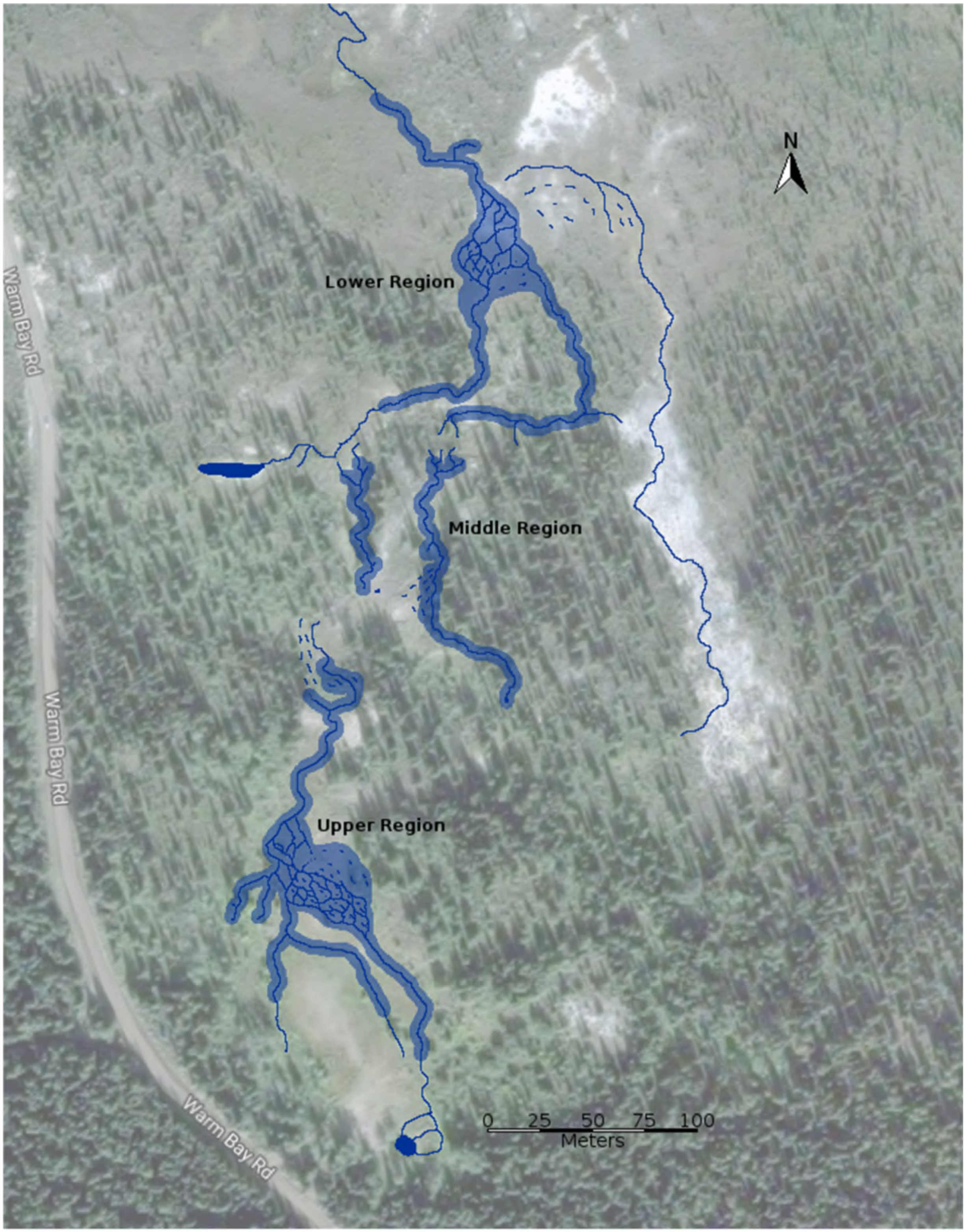

Figure 8. Modified satellite image of the Atlin Warm Springs (courtesy of A. deBruyn).

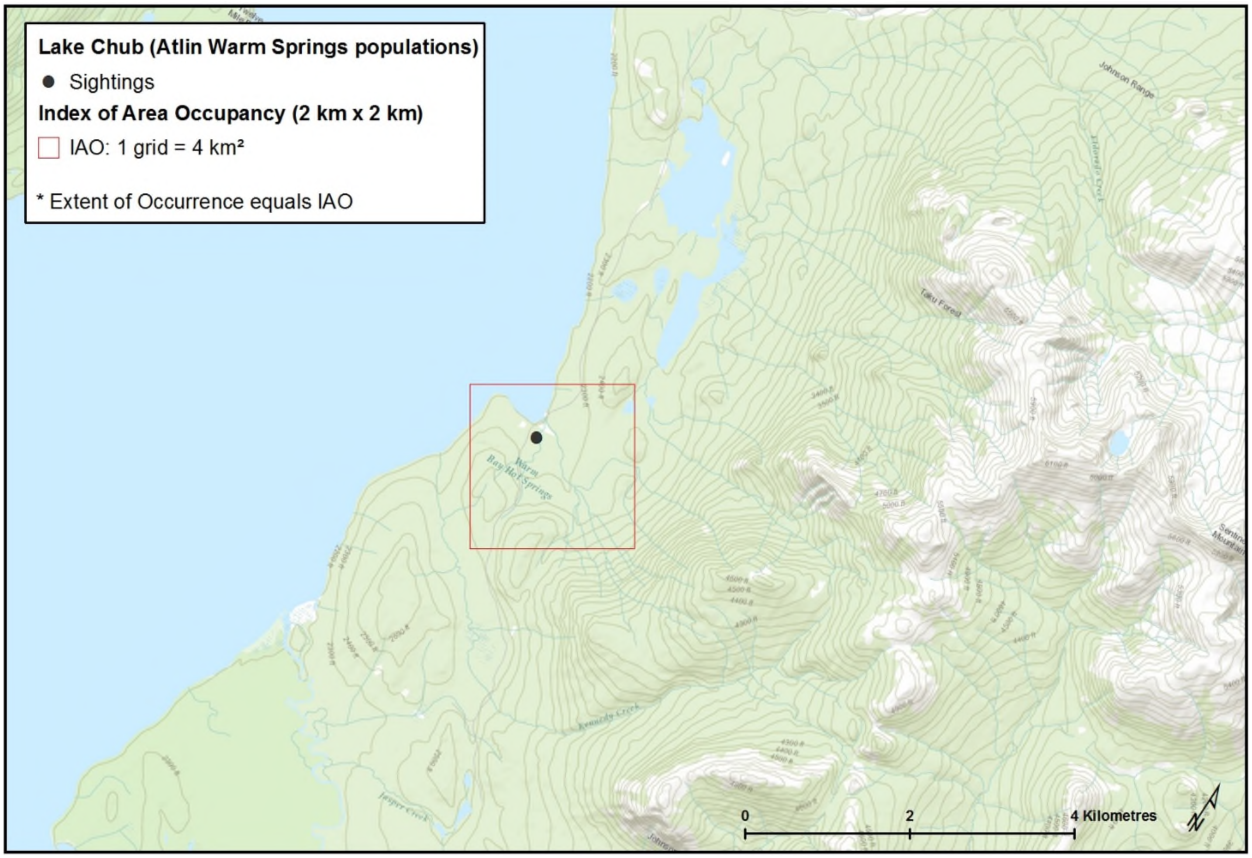

Figure 9. Estimate of the extent of occurrence and index of area of occupancy for the Atlin Warm Springs Lake Chub DU.

Lake Chub are broadcast spawners with non-adhesive demersal eggs (Brown *et al.* 1970; Fuiman and Baker 1981). Spawning has been observed during the months of May through August with later spawning towards the northern edge of the species' range (Geen 1955; Brown *et al.* 1970; McPhail and Lindsey 1970; Scott and Crossman 1973; Stewart *et al.* 1982). Both sexes develop tubercles during the breeding season. Breeding males from east of the continental divide develop distinct red patches on the inner base of the pectoral fins, but in the west these red patches are absent (McPhail and Lindsey 1970; Scott and Crossman 1973). Spawning appears to involve an annual migration from deep water to shallow in lakes or from lakes into streams beginning in the spring following ice breakup as water temperatures approach 4°C (Brown *et al.* 1970). Inshore movements begin in the morning peaking in the late afternoon (Brown *et al.* 1970). Spawning in Saskatchewan lakes appears to commence once water temperatures reach 10°C. Spawning and courtship behaviour have been reported for Lake Chub in Lac la Ronge, Saskatchewan where there are multiple males to each female in spawning aggregations (Brown *et al.* 1970). During courtship, males approach and attempt to pin females against rocks. The males then vibrate vigorously against the females resulting in the release of a few eggs that are fertilized. Females are fractional spawners and, although fecundity can range from 500 to 2400 eggs (depending on body size), release only a few eggs per spawning event. Males remain on the spawning grounds longer than females (Brown *et al.* 1970). Ripe egg diameter averages 1.8 to 2.4 mm (Brown *et al.* 1970; Fuiman and Baker 1981). Eggs hatch in about 10 days when held at temperatures between 8 and 19°C (Brown *et al.* 1970). Newly hatched larvae are about 6 mm long (Geen 1955; Fuiman and Baker 1981).

Physiology and Adaptability

Lake Chub as a species is widely distributed and so is able to persist in a wide range of thermal environments ranging from Arctic watersheds to temperate lakes and streams to hot springs, indicating considerable flexibility in temperature tolerance. However, Lake Chub predominate in Arctic watersheds (Figure 3) and such a northern distribution suggests that they are cold-adapted, especially compared to other cyprinid species (Scott and Crossman 1973). Furthermore, hot springs populations are only known from upper Liard and upper Yukon rivers, demonstrating that populations adapted to such habitats are rare.

Lake Chub possess physiological and life history traits that are adapted for life in subarctic and arctic environments. Northern populations of Lake Chub have been observed actively foraging at temperatures of less than 2ºC (McPhail 2001). In contrast, most minnows reduce their activity and food intake at water temperatures below 10°C (Kelsch and Neill 1990). Late fall maturation of gonads prior to spawning the following summer is normal in Lake Chub (Ahsan 1966; Brown *et al.* 1970; McPhail 2001). Both of these characteristics, cold-water foraging and early maturation of gonads, are likely adaptations to the short northern growing season.

The majority of Lake Chub populations live in lakes and streams that experience an environment with strong seasonal variation in water temperature ranging from approximately 4ºC in the winter to the mid-20s (ºC) in the summer. In contrast, thermal-spring populations experience much more stable thermal conditions. Atlin Warm Springs maintain a relatively constant water temperature of 23 to 25ºC year-round but yearly average daily air temperature of 0.5ºC (Darveau *et al.* 2012). Daily average air temperatures range between -15º and -5ºC from December to March, and between 6º and 13ºC from May to September. Therefore, Darveau *et al.* (2012) hypothesized that thermal-spring populations would encounter relaxed selection for thermal plasticity and thermal breadth predicting that they would have narrower thermal breadth (a smaller difference between the maximum and minimum thermal tolerance) and that the extent of phenotypic plasticity would be reduced, both at the individual and metabolic levels. They tested warm-water spring and temperate-lake habitat populations and performed an acclimation experiment to assess population-level differences in maximum and minimum critical temperature tolerance and their capacity to acclimate, as well as muscle metabolic enzyme acclimation response. Darveau *et al.* (2012) found that both hot and warm spring colonists exhibit diverse physiological phenotypes associated with acclimation to environmental temperature. At the individual level, critical thermal tolerance varied as a function of the habitat thermal regime, where the stable-spring population had a reduced tolerance and the variable-spring habitat population showed a slightly improved tolerance. However, the differences were not reflected at all environmental temperatures and the mechanism driving the diversity could be a result of local adaptation or irreversible developmental plasticity. In either case, ecological isolation based on thermal tolerance was the expected outcome. Atlin Warm Springs fish acclimated to their habitat temperature (~25ºC) cannot tolerate temperatures below 8ºC, unless they acclimate beforehand. At the cellular level, the phenotypic plasticity of aerobic energy metabolism in response to acclimation temperature varied as expected where the extent of the physiological response is a function of the extent of environmental variability. In other words, the Atlin Warm Springs fish showed no change in mitochondrial enzyme activity with cold acclimation, suggesting a loss of phenotypic plasticity. In addition, the Atlin Warm Springs population showed a greater reduction in the breadth of thermal tolerance at high acclimation temperatures. Thus, populations from variable habitats might be selected to maintain cold tolerance even when acclimated to warm temperatures while populations from the constant warm habitat benefit by reducing cold tolerance except when acclimated to cold conditions. It is evident that the thermal regime results in local adaptation that ultimately affects the physiological phenotypes of the species (Darveau *et al.* 2012).

Dispersal and Migration

Lake Chub are known to make seasonal movements within a lake or from lake to river or stream for their annual spawning migration (Brown *et al.* 1970; Scott and Crossman 1973; Reebs *et al*. 1995). Within Lac la Ronge, Brown (1969) reports that marked Lake Chub freely dispersed within 3.2 km of the tagging site but were not captured elsewhere in the lake. Seasonally, Lake Chub moved into shallower water in July, August, and early September (likely for spawning) but subsequently moved offshore and were not readily captured (Brown 1969). Seasonal spawning migration appears to be regulated by water temperature with movements beginning once minimum daily temperature reached 8ºC (Reebs *et al.* 2008).

The confined habitats of the hot springs limit migration and dispersal. The Liard Hot Springs complex has no obvious connections to other lakes or streams; its outflow is contained entirely within the adjacent swamps and flooded forest (McPhail 2001) although there may have been access to the Liard River prior to the construction of the Alaska Highway. Lake Chub are apparently absent in the portion of the upper Liard River adjacent to the Liard Hot Springs (FISS 2004; McPhail, pers. comm. to Taylor and Stamford, 2004). Therefore, there is very limited habitat within which the Lake Chub are able to disperse. It is unknown if they make any type of annual spawning migration. Differences in sex ratios and severity of blackspot infection between Lake Chub in Alpha Swamp, Delta Pool, and Epsilon Pool suggest that there may be three geographically isolated subpopulations within the Liard Hot Springs complex (McPhail 2001) and limited movement of Lake Chub between the pools in the hot springs complex. Some movement between the adjacent Delta-Epsilon Complex and alpha swamp may occur when beaver activity raises water levels.

Earlier observations indicated that the outlet stream of the Atlin Warm Springs gradually dissipated until it neared Atlin Lake (McPhail pers. comm. to Taylor and

Stamford 2004). However, there is currently a continuous stream that connects the Lake Chub inhabited region of the warm springs to the lake (flowing under the Warm Bay road through a culvert). However, it is unknown whether fish would venture downstream into the cold water or vice versa from Atlin Lake into the thermal waters of the warm springs. Whether the respective populations could tolerate and survive in the unfamiliar thermal environment is unknown.

Interspecific Interactions

Scott and Crossman (1973) report several species of fishes feeding on Lake Chub including Northern Pike (*Esox lucius*), Lake Trout (*Salvelinus namycush*), Burbot (*Lota lota*), and Walleye (*Sander vitreum*). However, Brown (1969) reports no evidence of Lake Chub in many predatory fish stomachs examined in Lac la Ronge but notes the presence of alternative more readily taken prey items. White (1953) documented kingfishers and mergansers preying on Lake Chub in eastern Canada. Other piscivorous birds such as loons, herons, eagles, and cormorants likely also consume Lake Chub (Steinmetz *et al.* 2003). Reebs *et al.* (1995) suggests that Lake Chub are more active at night and this behaviour may be an adaptation to avoid predation by birds. Fish-eating mammals (e.g., mink, martens, otters, fishers, raccoons) undoubtedly opportunistically consume Lake Chub. Staskiak (2006) suggests that in confined small ponds and headwater streams, predatory insects such as diving beetles (Dytiscidae), giant water bugs (Belostomatidae), and dragonfly (Odonata) larvae might be important predators, especially on larval and juvenile Lake Chub. Fish-eating snakes, turtles and amphibians also occur in small ponds and streams where Lake Chub are found and are likely predators. Stasiak (2006) notes that Lake Chub have the morphological characteristics of a visual predator and are typically one of the larger insectivores in the aquatic community. Lake Chub have been found to consume several kinds of zooplankton, stoneflies (Plecoptera), caddisflies (Trichoptera), dragonflies (Odonata), beetles (Coleoptera), and midges (Diptera). Brown *et al.* (1970) also report that spawning Lake Chub frequently cannibalized their own eggs.

There is no evidence of other fish species present in the Liard Hot Springs DU (Craig and Bruce 1983; McPhail 2001). In contrast to other populations that are primarily carnivorous feeding mainly on aquatic insect larvae (McPhail 2001), the Liard Hot Springs Lake Chub appear to be herbivorous, their diet consisting mainly of filamentous algae and *Chara sp.* (McPhail 2001). Some Lake Chub in the Delta-Epsilon complex also feed on organics in mud until their stomachs fill to distension (McPhail 2001). The flatworm larvae (*Neascus sp.*) also known as black spot disease has affected a significant proportion of the Liard Hot Springs Lake Chub apparently contributing to a higher mortality of males (McPhail 2001). The life cycle has a fish-eating bird as definitive host, snail as first intermediate host and a fish as second intermediate host, and so may be linked to the presence of the endangered Hotwater Physa, also present in the thermal springs.

The non-native Cherry Shrimp (*Neocaridina davidi*) was first observed in the Atlin Warm Springs in 2015. It is normally an aquarium species and was presumably introduced from a discarded freshwater aquarium (A. deBruyn, pers. comm. March 2018). The population has grown exponentially and appears to have become an important food item for the Lake Chub in this DU. Atlin Warm Springs Lake Chub have also been observed to feed on snails.

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

No surveys or systematic attempts to quantify the abundance Liard Hot Springs DU exist. Estimates of the abundance of the Liard Hot Springs Lake Chub population are based primarily on anecdotal visual observations by biologists or other researchers. However, Brown (1969) notes that Lake Chub are shy and cryptic often hiding under cover and so may be difficult to assess visually.

The abundance of the Atlin Warm Springs Lake Chub population was recently estimated by conducting a mark-recapture study that also assessed movement and dispersal of individuals (A. deBruyn, pers. comm. March 2018).

Abundance

The absolute number of Lake Chub in the Liard Hot Springs DU is not known but they are very abundant and may number in the thousands (McPhail pers. comm. to Taylor and Stamford 2004). However, the skewed sex ratios and population sub-divisions observed for Lake Chub in the Liard Hot Springs complex (McPhail 2001) suggest that the effective population sizes are small compared to the total population size. Construction of a parking lot in the provincial park apparently killed an unknown proportion of the total population of Lake Chub in Liard Hot Springs, but there is no recent evidence of significant changes in population abundance.

The population of Lake Chub living in the Atlin Warm Springs DU was estimated at several hundred in September 2000 (McPhail, pers. comm. to Taylor and Stamford 2004). A recent mark-recapture study estimated the abundance of this population at between 1500 and 2200 individuals, but it is believed to be conservative (A. deBruyn, pers. comm. March, 2018). Atlin Warm Springs have occasionally been excavated to maintain the quality of the main pool for bathing (R. Keim, pers. comm. to Taylor and Stamford 2004) but there are no data on whether these excavations have affected Lake Chub abundance.

Fluctuations and Trends

As noted above, there are no data available to determine trends in abundance within any of the thermal springs within the two DUs.

Rescue Effect

Given the unique physiological adaptations that the populations inhabiting the hot and warm springs have evolved (Darveau *et al.* 2012; Taylor *et al.* 2013), the probability of successfully rescuing any of these populations by transplanting Lake Chub from other cold-water adapted populations is remote. In addition, there are physical barriers to any potential natural dispersion of Lake Chub into both the hot and warm springs DU.

THREATS AND LIMITING FACTORS

Threats

The main ongoing threat to cold-water Lake Chub is that of water quality and availability (Stasiak 2006). Lake Chub prefer clean clear water and any activities that remove water for human consumption, increase turbidity, or introduce pollutants would adversely affect Lake Chub populations. The other major threat appears to be introduction of predator species particularly centrarchids (Sunfish, Bass) that overlap with Lake Chub in the littoral zone of lakes and have substantially reduced Lake Chub abundance in some systems (Stasiak 2006). Although not as extensively studied, similar threats are expected to exist for the hot springs populations assessed here. Threats were assessed as High to Low for both DUs (Appendix 1 and 2).

<u>Liard Hot Springs DU</u>

Invasive non-native/alien species/diseases

The introduction of a non-native species to the hot springs complex could have severe impacts depending on the species, including predation, competition, introgression, disease and habitat alteration. For example, the extinction of the Banff Longnose Dace (*Rhinicthys cataractae smithi*) from the hot springs at Banff National Park, Banff, Alberta (Lanteigne 1987) came about after the deliberate introduction of Mosquitofish (*Gambusia affinis*) in the 1920s, followed by various tropical fish, created competition and predation of the eggs and young dace. Subsequent hybridization with Eastern Longnose Dace (*Rhinichthys cataractae*) led to its disappearance by the late 1980s. Spring environments are by nature fragile ecosystems that could easily suffer irreversible impacts because of their very limited size and reliance on a constant replenishment of spring-fed water. An introduction of Goldfish (*Carassius auratus*) or related common Carp/Koi (*Cyprinus carpio*) could have significant ramifications on such an environment and the single species of fish that inhabits it. These cyprinids are notorious for disturbing habitat and increasing turbidity; for a sight-dependent forager like Lake Chub this could have impacts on their ability to feed. They may also compete with Lake Chub for food or inadvertently feed on their eggs. Non-native, warm water species such as Centrarchids (Bluegill Sunfish, Black Crappie, Yellow Perch, Smallmouth and Largemouth Bass) which overlap in habitat use of lakes (i.e., littoral zone) with Lake Chub could decimate their populations should they be introduced (Stasiak 2006). Several centrarchid species have already been introduced in many southern and central areas of British Columbia. The warmer waters of the springs may provide an amenable environment for these predatory species, some of which are usually limited to more temperate conditions than found in northern watersheds. Non-native fish can also introduce pathogens to naïve isolated populations.

Such introductions are happening in other waterbodies at an increasing rate as more people access these locations for recreational or other purposes. For example the non-native Cherry Shrimp (*Neocaridina davidi*) was illegally introduced into Atlin Warm springs (see below). The impact of this threat was assessed as Large-Small (Appendix 1). This level of uncertainty derives from three sources. First, the degree of connectedness of the multiple pools in the complex is unknown, therefore the scope of the threat is uncertain. Second, there is uncertainty in the severity of the threat based on the relative impact of various species that may be illegally introduced. And finally, the timing is uncertain as we can't predict when an illegal introduction might happen.

Domestic and Urban Wastewater

Liard Hot Springs Provincial Park is a popular stop on the Alaska highway and the busiest park in northern BC (BC Ministry of Parks 1990). The 53 campsites and day use parking lot are frequently filled past capacity throughout the summer months. The heavy use of the park, and the isolation and restricted size of the Lake Chubs' unique thermal environment make recreational human use of the park a potential threat to Liard Hot Springs Lake Chub. Although the use of soap and shampoo is prohibited in the hot springs, bathers are not supervised by park staff and may introduce toxins into the water. Deleterious substances that might be added to the hot springs ecosystem by visitors include lantern fuel, suntan lotions, insect repellant, and bath oils. The amount of toxins added to the water on a routine basis is probably minor relative to the total volume of the hot springs complex, so the impact of these substances should be reduced through dilution. Recent testing for aggregate organics by BC government researchers found trace to 2.3 mg/L in the hot springs. There was also no evidence of tricosan, an anti-microbial chemical common in shampoos, deodorants, and toothpaste (G. Wilson, pers. comm. 2018). The park's Master Plan (BC Ministry of Parks 1990) suggests that there will not be significantly increased development within the park (i.e., no new parking). However, increased development of private campgrounds and accommodation outside the park will continue to increase recreation demands within the park. The threat from water pollution was rated as negligible over the next ten years but ongoing and has the potential to impact a large portion of the population (Appendix 1).

<u>Atlin Warm Springs DU</u>

Invasive non-native/alien species/diseases

The introduction of invasive fish species to the Atlin Warm Springs could have a severe impact as noted above. In 2015, non-native Cherry shrimp (*Neocaridina davidi*), normally an aquarium species, was first found in the Atlin Warm Springs and has become an important food item for Lake Chub (A. deBruyn, pers. comm. March 2018). Additional concerns exist for this DU regarding introduction of other aquarium species, particularly the common Goldfish, or other warm-water non-native species. Introduction of turtles into the hot spring is a concern although Lake Chub co-occur with them in many non-thermal environments. As discussed for the Liard Hot Springs populations, the impact of this threat was assessed as Large-Small (Appendix 2). This level of uncertainty derives from three sources. First, the degree of connectedness across the thermal spring area is unknown and therefore the scope of the threat is uncertain. Second, there is uncertainty in the severity of the threat based on the relative impact of various species that may be illegally introduced. And finally, the timing is uncertain as we can't predict when an illegal introduction might happen.

Domestic and Urban Wastewater

The Atlin Warm Springs are in regular use for bathing by both tourists and residents of the nearby town of Atlin. The same issues around the introduction of toxins associated with insect repellants, suntan lotion, shampoo, and soaps exist as in the Liard Hot Springs DU although the potential for dilution in the smaller pool is diminished. The threat from water pollution was rated as unknown because of uncertainty about the timing of effects over the next ten years although ongoing and potentially affecting a large portion of the population (Appendix 2).

Other Ecosystem Modifications

Atlin Warm Springs have occasionally been excavated to maintain the quality of the main pool for bathing (R. Keim, pers. comm. to Taylor and Stamford 2004). There are reports that the temperature of the water decreased after excavation activity that occurred in the late 1980s (R. Keim, pers. comm. to Taylor and Stamford 2004), but in 2000, the springs were still hot (21 to 25ºC) and intact (McPhail 2001). It is expected that maintenance excavation activity will continue and poses an ongoing threat to the Lake Chub population at that site. On the other hand, dredging may have some positive effects by maintaining pools that might otherwise silt in and reduce the available Lake Chub habitat. The threat was rated as negligible because of uncertainty in timing over the next ten years. The threat is ongoing but likely to impact only a small portion of the population (Appendix 2).

Limiting Factors

<u>Habitat Carrying Capacity</u>

The available hot springs habitat is a limiting factor in terms of how large the Lake Chub populations may become in either the Liard and Deer Rivers Hot Springs or the Atlin Warm Springs. All three sites are relatively confined areas that limit the carrying capacity of these habitats for Lake Chub.

<u>Geological Instability</u>

Due to their narrow temperature tolerance a limiting factor for Lake Chub populations is the natural change in temperature or flow rates in either of the two DUs. The Atlin Warm Springs are adjacent to the Pacific tectonic fault and so experience frequent earthquake events. It is evident that other hot springs have shown changes in thermal regime because of local or more distant geological activity (Cox *et al*. 2015; Ma 2016). Such changes in the local environment for Lake Chub could have detrimental impacts on their abundance or pose limits to ongoing viability of the populations.

Parasites

McPhail (2001) noted that the sex ratio favoured females in Liard Hot Springs and argued that the prevalence of infestation with black spot disease may have increased mortality of male Lake Chub there. There is no evidence that black spot infection is lethal in other species or populations of fish in non-thermal environments. However, if parasitic infestation is contributing to the higher mortality of adult male fish in hot springs then the population is limited by the extent of the parasitism.

Number of Locations

Liard Hot Springs DU

Lake Chub found in the Liard Hot Springs are at risk due to the ease and extent of human access. The most imminent and ongoing threats are the introduction of invasive species and water quality resulting from increased human use of the springs for bathing. Parasitism due to black spot disease is both a threat and limiting factor that appears to be greatest in the Liard Hot Springs population. However, there is considerable uncertainty about the extent and impact of each of these threats to the Liard Hot Springs Lake Chub. As a result, there is a single location in the DU that is exposed to threats affecting most or all individuals in the populations.

Atlin Warm Springs DU

Lake Chub found in the Atlin Warm Springs exist at a single site and are exposed to the same threats as the Liard Hot Springs location, i.e., introduction of invasive species and human induced toxins from bathing. While the extent and magnitude of these threats in the DU are uncertain, there is a single location that is exposed to threats affecting most or all individuals in the population.

PROTECTION, STATUS AND RANKS

Legal Protection and Status

In this report, the thermal springs Lake Chub populations have been separated into two DUs. The entire Liard Hot Springs thermal complex is contained within Liard Hot Springs Provincial Park. The Deer River Hot Springs are contained within the adjacent Liard River Corridor Provincial Park. Thus, these two sites of hot springs associated with Lake Chub are protected by the *Park Act* of BC that sets management guidelines and restricts resource extraction within Provincial Parks.

The Atlin Warm Springs DU is not contained within a provincial park and so is not afforded these protections.

Non-Legal Status and Ranks

NatureServe gives Hot Springs Lake Chub populations a conservation status of G5T2 (Natureserve 2016), globally secure but imperilled. The provincial listing by the BC Conservation Data Centre in 2011 is S2 or imperilled and they are red-listed.

NatureServe assigned the non-Hot Springs Lake Chub a global status rank of secure (G5) and national status ranks of secure (N5) for Canada and the United States (NatureServe 2016). However, in the United States Lake Chub have not been listed nationally but State Heritage Status ranks have been determined for 18 states: secure (S5) or apparently secure (S4) in six states, vulnerable to critically imperilled (S3 to S1) in eight states (Colorado, Indiana, Massachusetts, Nebraska, New York, North Dakota, South Dakota, and Washington), extirpated (SX) in Iowa while Idaho, Illinois, and Minnesota are under review (NatureServe 2016).

Provincial Heritage rank of secure (S5) has been assigned for all subregions of Canada except Labrador (Newfoundland) where a status of rare – uncommon (S3S4) is assigned, unknown (SU) for Nunavut and PEI where the species does not occur (NatureServe 2016). The BC Conservation Data Centre gives cold-water Lake Chub a rank of secure or not at risk (Yellow).

Habitat Protection and Ownership

The Liard Hot Springs Lake Chub are contained within the Liard River Hot Springs Provincial Park. Provincial Parks are Crown land managed by BC Parks. The *Park Act* of BC, which sets management guidelines and restricts resource extraction within provincial parks, provides protection against serious habitat degradation or loss. The Master Plan created for Liard River Hot Springs Provincial Park in 1990 (BC Ministry of Parks 1990) specifically identifies both the endemic snail Hotwater Physa and the Hot Springs Lake Chub as in need of protection, recognizes their vulnerability, and commits to management actions that will maintain the existing hydrological conditions to sustain these two species. The Hotwater Physa and its habitat is protected as an endangered species under the *Species at Risk Act* on federal lands, which doesn't apply in these locations so Lake Chub is unprotected although they share the same limited habitat. Interestingly, a management plan for the Liard River Corridor Provincial Park makes no mention of the Lake Chub as a vulnerable species in need of protection (MOE 2009).

The Atlin Warm Springs are located on private lands with public access and has no specific habitat protections (Woodward 1999).

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Jacob (Jake) Schweigert received his B.Sc. (Honours) from the University of Toronto in 1974 and his M.Sc. (Zoology) from the University of Manitoba in 1976. Jake is Scientist Emeritus with Fisheries and Oceans Canada at the Pacific Biological Station (PBS), Nanaimo, British Columbia. Prior to his retirement, Mr. Schweigert was employed as a scientist with DFO since 1981 most recently as Section Head for Conservation Biology at PBS. Jake spent most of his career conducting research and stock assessment of Pacific herring and other forage species. He has authored or co-authored more than 30 publications in peer-reviewed scientific journals and over 70 other publications including the COSEWIC stock status reports for Pacific Sardine, Interior Fraser Coho Salmon, Sakinaw Lake Sockeye Salmon, and Westslope Cutthroat Trout.

Appendix 1. Threats Assessment for the Lake Chub, Liard Hot Springs populations.

Species or Ecosystem Scientific Name	Lake Chub - Liard Hot Springs Populations *Couesius plumbeus*		
Element ID		**Elcode**	
Date (Ctrl + ";" for today's date):	16/01/2018		
Assessor(s):	Jake Schweigert (writer), Dwayne Lepitzki (moderator), John Post (co-chair), Pete Cott, Doug Watkinson and Sue Pollard (SSC members), Greg Wilson (BC), Ross Claytor (fish biologist) and Angèle Cyr (COSEWIC Secretariat).		
References:	Threats telecon, 16 Jan 2018; draft report and threats calculator		

Overall Threat Impact Calculation Help:

Threat Impact		**Level 1 Threat Impact Counts** **high range**	**low range**
A	Very High	0	0
B	High	1	0
C	Medium	0	0
D	Low	0	1
	Calculated Overall Threat Impact:	High	Low

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
3	Energy production & mining		Not Calculated (outside assessment timeframe)	Unknown	Unknown	Low (Possibly in the long term, >10 yrs/3 gen)	
3.1	Oil & gas drilling						
3.2	Mining & quarrying						
3.3	Renewable energy						
4	Transportation & service corridors						
4.1	Roads & railroads						
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
5.1	Hunting & collecting terrestrial animals						NA
5.2	Gathering terrestrial plants						NA
5.3	Logging & wood harvesting						NA- recharge zone outside the park and have no information about logging
5.4	Fishing & harvesting aquatic resources		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	collection prohibited in Park but could be some dip net collection.
6	Human intrusions & disturbance		Negligible	Restricted - Small (1-30%)	Negligible (<1%)	High (Continuing)	
6.1	Recreational activities		Negligible	Restricted - Small (1-30%)	Negligible (<1%)	High (Continuing)	low probability of encounter
6.2	War, civil unrest & military exercises						NA
6.3	Work & other activities		Negligible	Restricted (11-30%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Scientific collections of fish and snails but these are non-lethal sampling
7	Natural system modifications		Not Calculated (outside assessment timeframe)	Restricted (11-30%)	Serious (31-70%)	Low (Possibly in the long term, >10 yrs/3 gen)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7.1	Fire & fire suppression						NA - no info on fire and suppression history unknown
7.2	Dams & water management/use		Not Calculated (outside assessment timeframe)	Restricted (11-30%)	Serious (31-70%)	Low (Possibly in the long term, >10 yrs/3 gen)	There is a weir separating upper/lower Alpha Pool; lower Alpha Pool/Alpha Stream; a second berm was constructed within Alpha Stream approximately 15 metres downstream of the weir but doesn't really affect pool water. There is a proposal for water withdrawal but it is unlikely to be approved.
7.3	Other ecosystem modifications		Negligible	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	Dredging for swimming
8	Invasive & other problematic species & genes	BD	High - Low	Large - Small (1-70%)	Serious - Slight (1-70%)	High - Low	
8.1	Invasive non-native/alien species/diseases	BD	High - Low	Large - Small (1-70%)	Serious - Slight (1-70%)	High - Low	There is concern for introductions of goldfish or other warm water non-native species.
8.2	Problematic native species/diseases						black spot is a limiting factor
8.3	Introduced genetic material						
8.4	Problematic species/diseases of unknown origin						
8.5	Viral/prion-induced diseases						
8.6	Diseases of unknown cause						
9	Pollution		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	
9.1	Domestic & urban waste water		Unknown	Large (31-70%)	Unknown	High (Continuing)	human contamination by bathers, but could be positive with nutrient input or negative from oils, DEET etc.
9.2	Industrial & military effluents						
9.3	Agricultural & forestry effluents						
9.4	Garbage & solid waste		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	some garbage but it is picked up so not persistent
9.5	Air-borne pollutants						
9.6	Excess energy						
10	Geological events						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
10.1	Volcanoes						
10.2	Earthquakes/tsunamis						NA - not a high risk earthquake zone.
10.3	Avalanches/landslides						
11	Climate change & severe weather		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
11.1	Habitat shifting & alteration						
11.2	Droughts						
11.3	Temperature extremes						
11.4	Storms & flooding						
11.5	Other impacts						

Classification of Threats adopted from IUCN-CMP, Salafsky *et al.* (2008).

Appendix 2. Threats Assessment for the Lake Chub, Atlin Warm Springs populations.

Species or Ecosystem Scientific Name	Lake Chub - Atlin Warm Springs Populations *Couesius plumbeus*			
Element ID		**Elcode**		
Date (Ctrl + ";" for today's date):	16/01/2018			
Assessor(s):	Jake Schweigert (writer), Dwayne Lepitzki (moderator), John Post (co-chair), Pete Cott, Doug Watkinson and Sue Pollard (SSC members), Greg Wilson (BC), Ross Claytor (fish biologist) and Angèle Cyr (COSEWIC Secretariat).			
References:	Threats telecon, 16 Jan 2018; draft report and threats calculator			

Overall Threat Impact Calculation Help:			**Level 1 Threat Impact Counts**	
	Threat Impact		**high range**	**low range**
	A	Very High	0	0
	B	High	1	0
	C	Medium	0	0
	D	Low	0	1
		Calculated Overall Threat Impact:	High	Low

Threat		**Impact (calculated)**		**Scope (next 10 Yrs)**	**Severity (10 Yrs or 3 Gen.)**	**Timing**	**Comments**
1	Residential & commercial development						
1.1	Housing & urban areas						
1.2	Commercial & industrial areas						
1.3	Tourism & recreation areas						Unknown but near enough to Atlin that development potential exists
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						
2.2	Wood & pulp plantations						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
2.3	Livestock farming & ranching						
2.4	Marine & freshwater aquaculture						
3	Energy production & mining		Not Calculated (outside assessment timeframe)	Unknown	Unknown	Low (Possibly in the long term, >10 yrs/3 gen)	
3.1	Oil & gas drilling		Not Calculated (outside assessment timeframe)	Unknown	Unknown	Low (Possibly in the long term, >10 yrs/3 gen)	The area is currently undeveloped. Concern is deep well drilling and production via horizontal drilling and/or hydraulic fracturing could; A) contaminate source water with fracking fluids, b) disrupt current thermal spring flow volume (and/or temperature), or 3) increased seismic activity which could also disrupt or change the underground flow patterns.
3.2	Mining & quarrying						
3.3	Renewable energy						
4	Transportation & service corridors						
4.1	Roads & railroads						
4.2	Utility & service lines						
4.3	Shipping lanes						
4.4	Flight paths						
5	Biological resource use		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
5.1	Hunting & collecting terrestrial animals						
5.2	Gathering terrestrial plants						
5.3	Logging & wood harvesting						
5.4	Fishing & harvesting aquatic resources		Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Readily accessible by road from Atlin so some dip net collection may occur.
6	Human intrusions & disturbance		Negligible	Restricted - Small (1-30%)	Negligible (<1%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
6.1	Recreational activities		Negligible	Restricted - Small (1-30%)	Negligible (<1%)	High (Continuing)	low probability of encounter
6.2	War, civil unrest & military exercises						
6.3	Work & other activities		Negligible	Restricted (11-30%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	scientific collections of fish but these are non-lethal sampling
7	Natural system modifications		Not Calculated (outside assessment timeframe)	Restricted (11-30%)	Serious (31-70%)	Low (Possibly in the long term, >10 yrs/3 gen)	
7.1	Fire & fire suppression						no info on fire and suppression history unknown
7.2	Dams & water management/use						
7.3	Other ecosystem modifications						
8	Invasive & other problematic species & genes	BD	High - Low	Large - Small (1-70%)	Serious - Slight (1-70%)	High - Low	
8.1	Invasive non-native/alien species/diseases	BD	High - Low	Large - Small (1-70%)	Serious - Slight (1-70%)	High - Low	Cherry shrimp have been released in the spring and there is concern for introductions of goldfish or other warm water non-native species.
8.2	Problematic native species/diseases						
8.3	Introduced genetic material						
8.4	Problematic species/diseases of unknown origin						
8.5	Viral/prion-induced diseases						
8.6	Diseases of unknown cause						
9	Pollution		Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	
9.1	Domestic & urban waste water		Unknown	Large (31-70%)	Unknown	High (Continuing)	Human contamination by bathers, but could be positive with nutrient input or negative from oils, DEET etc.
9.2	Industrial & military effluents						
9.3	Agricultural & forestry effluents						

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.4	Garbage & solid waste		Not Calculated (outside assessment timeframe)	Large (31-70%)	Slight (1-10%)	Low (Possibly in the long term, >10 yrs/3 gen)	some garbage but it is picked up so not persistent
9.5	Air-borne pollutants						
9.6	Excess energy						
10	Geological events		Not Calculated (outside assessment timeframe)	Pervasive (71-100%)	Extreme (71-100%)	Low (Possibly in the long term, >10 yrs/3 gen)	
10.1	Volcanoes						
10.2	Earthquakes/tsunamis		Not Calculated (outside assessment timeframe)	Pervasive (71-100%)	Extreme (71-100%)	Low (Possibly in the long term, >10 yrs/3 gen)	Atlin lies on the Pacific fault and experiences numerous earthquakes.
10.3	Avalanches/landslides						
11	Climate change & severe weather		Unknown	Pervasive (71-100%)	Unknown	High (Continuing)	
11.1	Habitat shifting & alteration						
11.2	Droughts						
11.3	Temperature extremes						
11.4	Storms & flooding						
11.5	Other impacts						

Classification of Threats adopted from IUCN-CMP, Salafsky *et al.* (2008).

Appendix 3. Satellite image of the Liard Hot Springs (taken from Google Maps, March 2018).

Appendix 4. Photo of habitat showing the Alpha stream at the swamp in the Liard Hot Springs (courtesy G. Wilson).

Appendix 5. Photo of habitat showing the Gamma Pool at the Delta-Epsilon complex in the Liard Hot Springs (courtesy G. Wilson).

Appendix 6. Photo of habitat showing the Delta stream at the southern edge of the Delta-Epsilon complex in the Liard Hot Springs (courtesy G. Wilson).

Appendix 7. Satellite image of the Atlin Warm Springs (taken from Google Maps, March 2018). Atlin Lake in the upper left of the image.

Appendix 8. Photo of the Atlin Warm Springs (downloaded from http: \\theroadchoseme.com/atlin-warm-springs, March 2018).