Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Pacific Region

Canadian Science Advisory Secretariat
Science Response 2021/008

RECOVERY POTENTIAL ASSESSMENT FOR LAKE CHUB (*COUESIUS PLUMBEUS*), LIARD HOT SPRINGS AND ATLIN WARM SPRINGS POPULATIONS

Context

After the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses an aquatic species as Threatened, Endangered or Extirpated, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the *Species at Risk Act* (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) that is conducted shortly after the COSEWIC assessment. This timing allows for consideration of peer-reviewed scientific analyses into SARA processes, including listing and recovery planning.

Liard Hot Springs and Atlin Warm Springs designatable units (DUs) or populations of Lake Chub (*Couesius plumbeus*) were assessed as Threatened by COSEWIC in the fall of 2018 (COSEWIC 2018). Although Lake Chub are the most widespread minnow in North America (McPhail 2007), the Liard Hot Springs and Atlin Warm Springs populations are confined to two unique thermal spring environments in northern British Columbia (McPhail 2007). Very little is known about these two populations. The state of knowledge is found within a few text books, field reports and the COSEWIC assessment. Normally when a RPA is undertaken a working paper is developed and a Canadian Science Advisory Secretariat (CSAS) regional peer review is held. Given the paucity of data and lack of both internal and external expertise, the Science Response format was chosen to summarize the information and respond to the elements of the Terms of Reference in the most efficient and effective way possible.

In support of listing recommendations for Lake Chub (Liard Hot Springs and Atlin Warm Springs populations), DFO Science has been asked to undertake a RPA, based on the national RPA Guidance. The advice in the RPA may be used to inform both scientific and socio-economic aspects of the listing decision, development of a recovery strategy and action plan, and to support decision making with regards to the issuance of permits or agreements, and the formulation of exemptions and related conditions, as per sections 73, 74, 75, 77, 78 and 83(4) of SARA. The advice in the RPA may also be used to prepare for the reporting requirements of SARA s.55. The advice generated via this process will update and/or consolidate any existing advice regarding these two populations of Lake Chub.

The RPA provides up-to-date information and discusses associated uncertainties of the 22 elements of the terms of reference under the following categories:

- Biology, abundance, distribution and life-history parameters
- Habitat and residence requirements
- Threats and limiting factors to survival and recovery
- Recovery targets
- Scenarios for mitigation of threats and alternatives to activities

- Allowable harm

This Science Response results from the Science Response Process of April 14, 2020 on the Recovery Potential Assessment – Lake Chub - Liard Hot Springs and Atlin Warm Springs Designatable Units.

Analysis and Response

Biology, Abundance, Distribution and Life-History Parameters

Element 1: Summarize the biology of Lake Chub (Liard Hot Springs and Atlin Warm Springs populations)

Lake Chub, *Couesius plumbeus*, are in the minnow family (Cyprinidae) and were first described by Agassiz (1850) as *Gobio plumbeus*. Historically, *Couesius plumbeus* was considered to include three subspecies: *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. Insufficient understanding of their complex intraspecific relationships has resulted in the use of *C. plumbeus* for all three forms (Scott and Crossman 1973, Wells 1978). Although the origin of Lake Chub in the Liard River, which forms the hub of the northern BC Hot Springs Lake Chub distribution, is uncertain (McPhail and Carveth 1992), Wells (1978) speculated that the region may be an area of intergradation between the *C. p. greeni* and *C. p. dissimilis* forms.

Although Lake Chub are the most widespread minnow in North America (McPhail 2007) and considered a cold-water fish species, very little information is known about the Liard Hot Springs and Atlin Warm Springs populations. Therefore, information within this report pertains to Lake Chub in general, unless otherwise stated. Lake Chub are 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). Lake Chub typically mature at age 3–4 rarely living beyond age 5. Several records of 7-year-old fish exist, although scales were reportedly difficult to age (Scott and Crossman 1973, Stasiak 2006). Lake Chub have 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 posterior to that of the pelvic fins. 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).

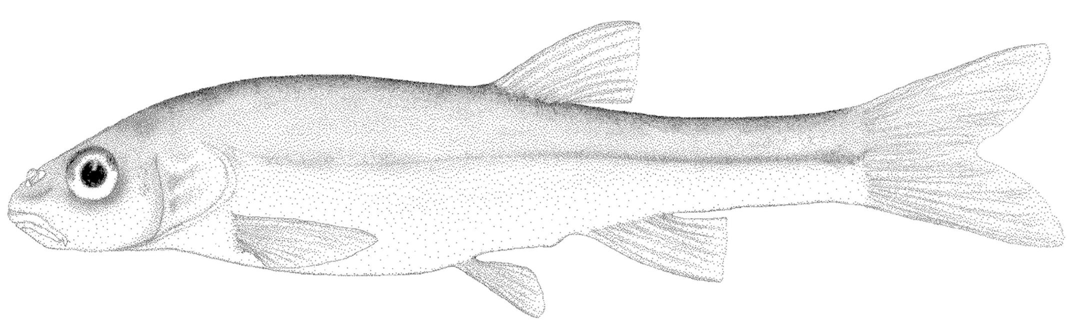

Figure 1. Drawing of a female Lake Chub, Couesius plumbeus, sampled from Alpha Swamp at the Liard Hot Springs in September 2000 (Illustrated by Diane McPhail). Reproduced from COSEWIC (2018).

Lake Chub are one of the most widely distributed freshwater fishes in North America. They are found from central Alaska in the west to Labrador in the east, with a northern range near the tree line, reaching a northern extreme in the Mackenzie River Delta (Figure 2). The southern extent of its range roughly follows the Canada-United States border. They occur in a patchy distribution through New England as far south as the upper Delaware River, and in the drainage basins of the Great Lakes. Lake Chub are absent from parts of southern Saskatchewan and Manitoba, and there are isolated relicts in the Rocky Mountains of Colorado (deBruyn 2019). Lake Chub are present in the upper branches of many Pacific-draining rivers, such as the Yukon, Stikine and Fraser rivers, but absent from coastal regions except in a small section of southeastern Alaska. The current distribution and diversity of Lake Chub is a result of recent glaciations, which restricted the species to several major refugia in Beringia, the Pacific coast, the Mississippi-Missouri system, and the Atlantic coast (Taylor et al. 2013). Phylogeographic evidence also indicates that unique intraspecific lineages of freshwater fish colonized the Liard system from a glacial refuge located in the adjacent Nahanni River Valley (Ford 1976; Lindsey and McPhail 1986; Foote et al. 1992; Stamford and Taylor 2004).

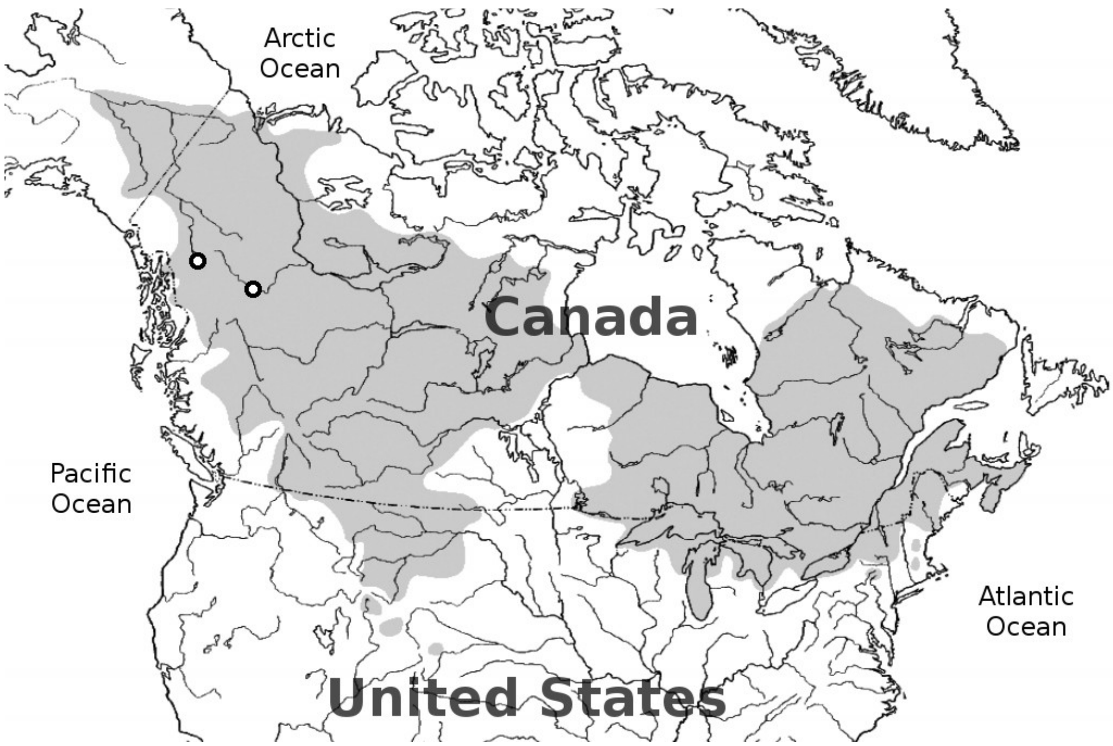

Figure 2. Range of the Lake Chub Couesius plumbeus, shaded in grey (Unpublished COSEWIC Status Report 2004). The general locations of thermal springs populated by Lake Chub in northwestern British Columbia are circled: the Atlin Warm Springs is the western circle on the Yukon River and the Liard River Hot Springs are represented by the circle to the east (Reproduced from deBruyn 2019).

There are three known hot springs Lake Chub populations or DUs, including the Liard Hot Springs and Atlin Warm Springs populations, all of which are located in the same COSEWIC National Ecological Area (Northern Mountains) in northern British Columbia. The upper Liard River system contains two of the hot springs associated with Lake Chub: the Liard Hot Springs located along the Alaska Highway in Liard Hot Springs Provincial Park and Deer River Hot Springs located in the adjacent Liard River Corridor Provincial Park. They are both in the western Arctic freshwater biogeographic zone. The Deer River Hot Springs population or DU has not been assessed by COSEWIC at this time and is not discussed further in this report. The third known hot springs Lake Chub population occurs in the Atlin Warm Springs near Atlin Lake in the Yukon River drainage within the Yukon freshwater biogeographic zone.

Lake Chub persist in a wide range of thermal environments in Canada 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 and such a northern distribution suggests that they are cold-adapted, especially compared to other cyprinid species (Scott and Crossman 1973). Furthermore, thermal springs populations are only known from upper Liard and upper Yukon rivers, demonstrating that populations adapted to such habitats are rare.

Lake Chub also possess physiological and life-history traits that are adapted for life in sub-Arctic 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 typical of 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 strong seasonal variation in water temperature ranging from approximately 4ºC in the winter to the mid-20ºC in the summer. In contrast, thermal-spring colonists experience much more stable thermal conditions. For example, Atlin Warm Springs maintain a relatively constant water temperature of 23–25ºC 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. 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 performed an acclimation experiment to assess population-level differences in maximum and minimum critical temperature tolerance and their capacity to acclimate. Darveau et al. (2012) found that both hot and warm spring colonists exhibited diverse physiological phenotypes associated with acclimation to environmental temperature. Atlin Warm Springs fish acclimated to their habitat temperature (~25ºC) cannot tolerate temperatures below 8ºC, unless they acclimate beforehand. The Atlin Warm Springs fish had undetectable changes 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. Therefore, 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.

Lake Chub are known to make seasonal movements within a lake or from lake to river or stream for the annual spawning migration that occurs in spring (Brown et al. 1970; Scott and Crossman 1973; Reebs et al. 1995). Seasonal spawning migration appears to be regulated by water temperature with movements beginning once minimum daily temperature reached 4–8ºC (Reebs et al. 2008). Following spawning Lake Chub move offshore and are not readily captured (Brown 1969). However, in general movement is limited and Brown (1969) reports that marked Lake Chub dispersed within 3.2 km of the tagging site in Lac La Ronge, Saskatchewan.

The confined habitats of the hot springs limit migration and dispersal. The Liard Hot Springs complex has no connections to other lakes or streams; its outflow is contained entirely within the adjacent swamps and flooded forest (McPhail 2001). Lake Chub are apparently absent in the portion of the upper Liard River adjacent to the Liard Hot Springs (FISS 2004; COSEWIC 2018; Stamford and Taylor 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 within this hot springs complex. Differences in sex ratios and severity of blackspot infection between Lake Chub in Alpha Swamp, Delta Pool, and Epsilon Pool (Figure 3) suggest that there are three geographically isolated subpopulations within the Liard Hot Springs complex (McPhail 2001) indicating that there is little or no movement of Lake Chub between pools in the hot springs complex. Some movement between the adjacent Delta and Epsilon pools may occur when beaver activity raises water levels. Extensive tagging experiments conducted in the Atlin Warm Springs during 2016 and 2017 also demonstrated little movement of Lake Chub throughout the system with the greatest distance between recaptures just over 100 m (de Bruyn 2019). Typically the movement was 25 m or less.

In contrast to cold-water populations that are primarily carnivorous feeding mainly on aquatic insect larvae, the Liard Hot Springs Lake Chub appear to be herbivorous, with a 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). Black Spot disease caused by flatworm larvae (*Neascus* sp.) has affected a significant proportion of the Liard Hot Springs Lake Chub (McPhail 2001). The parasite life cycle involves a fish-eating bird as definitive host, a snail as first intermediate host and a fish as second intermediate host. Hotwater Physa (*Physella wrighti*), an endangered snail endemic to the Liard Hot Springs complex, may therefore play a role in the infection of Lake Chub with Black Spot disease. Atlin Warm Springs Lake Chub have also been observed to feed on snails. In addition, the non-native Cherry Shrimp (*Neocaridina davidi*) was first observed in the Atlin Warm Springs in 2015. It is an aquarium species that was presumably introduced, has grown exponentially in population size, and has become an important food item for the Lake Chub (deBruyn 2019).

Element 2: Evaluate the recent species trajectory for abundance, distribution and number of populations

Liard Hot Spring

No surveys or systematic attempts to quantify the size of the Lake Chub populations have occurred to date in the Liard Hot Springs. Estimates of the abundance of the Liard Hot Springs Lake Chub population are based primarily on anecdotal visual observations by biologists or other researchers. The absolute number of Lake Chub in the Liard Hot Springs population are not known but they are abundant and may number in the thousands (COSEWIC 2018; Stamford and Taylor 2004). However, the skewed sex ratios and population sub-divisions observed for Lake Chub in the Liard Hot Springs complex suggest that the effective population sizes are small compared to the total population size (McPhail 2001). Construction of a parking lot in the provincial park may have resulted in some level of mortality historically for the population of Lake Chub in Liard Hot Springs (COSEWIC 2018). However, there is no recent evidence of significant changes in population abundance, but also no systematic surveys. Brown (1969) also notes that Lake Chub are shy and cryptic, often hiding under cover, and so may be difficult to assess visually. Consequently, the species trajectory and distribution are unknown. McPhail (2001) speculates that there may be three independent populations within the hot springs complex based on the distribution of the blackspot disease.

Atlin Warm Springs

The abundance of the Atlin Warm Springs Lake Chub population was estimated by a mark-recapture study conducted in 2016 and 2017 yielding a population size of between 1000–2000 individuals greater than 3 cm fork length but it is believed to be slightly higher (deBruyn 2019). It was also noted that the Lake Chub were cryptic and skittish when approached. Indications are that the life span is about 30 months but some may reach ages of 4 or 5 (deBruyn 2019). In the past, Atlin Warm Springs have occasionally been excavated to maintain the quality of the main pool for bathing (COSEWIC 2018; Stamford and Taylor 2004) but it is unknown whether these excavations have affected Lake Chub abundance. Consequently, the species trajectory is unknown. Tagging data indicate that there is limited movement among the pools or sections of the warm springs and deBruyn (2019) suggests that there may be three effectively distinct populations within the DU.

Element 3: Estimate the current or recent life-history parameters for Lake Chub (Liard Hot Springs and Atlin Warm Springs populations)

Thermal springs Lake Chub are shorter lived and mature earlier than those in cold-water environments. McPhail (2001) notes that fish larger than 70 mm are rare in thermal waters and by September most of the fish in the Liard Hot Springs were age 0 or 1 with few surviving to a third growing season compared to the 3–4 years reported for the Atlin Warm Springs (deBruyn 2019). It has also been found that females tend to live longer than males (COSEWIC 2018). It appears most fish hatched in the spring become sexually mature by September, i.e., they experience fast growth, early maturation and early death in the hot springs environment. The short life span makes these populations susceptible to interannual variation in recruitment.

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 in cold-water populations 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). Spawning appears to include an annual migration from deep water to shallow in lakes or from lakes into streams beginning in the spring following ice break up 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. 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).

The spawning period is not known for Liard Hot Springs but McPhail (2001) suggests that it is similar to cold-water populations. deBruyn (2019) reports that spawning occurs from late May until July in the Atlin Warm Springs. Lake Chub fry were observed in early-June. Based on the size frequency distribution, it appears that the majority of the Atlin Warm Springs population live for 3–4 years and sometimes to age 6 (deBruyn 2019). Gravid females exceeded 5.9 cm and 2.4 grams and ripe males 5.1 cm and 1.7 grams (deBruyn 2019). Sexual maturity occurred around 5 cm fork length and the mean length at age one was 4.9–5.8 cm (deBruyn 2019). Fecundity of the thermal springs populations is unknown.

Sex determination in fish is often influenced by incubation temperature (Conover and Kynard 1981). In the typical cold-water environments Lake Chub sex ratio is expected to be nearly equal (COSEWIC 2018). 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). 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. Since the sex ratio of Lake Chub in Atlin Warm Springs was 1:1, McPhail (2001) suggested that thermal environment was probably not the only factor influencing these inter-population differences. Within the Laird Hot Springs complex, the skew in sex ratio appeared to be associated with the prevalence of Black Spot disease. Alpha swamp had the lowest level, Epsilon Pool was moderate, and Delta Pool had the highest level. The Black Spot disease rate 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. McPhail (2001) speculates that the increased prevalence of males with Black Spot disease results in earlier mortality producing the skewed sex ratio.

Habitat and Residence Requirements

Element 4: Describe the habitat properties that Lake Chub (Liard Hot Springs and Atlin Warm Springs populations) needs for successful completion of all life-history stages. Describe the function(s), feature(s), and attribute(s) of the habitat, and quantify by how much the biological function(s) that specific habitat feature(s) provides varies with the state or amount of habitat, including carrying capacity limits, if any

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, 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 deep-water areas, except where the deep-water zone is anoxic 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, only rarely being found in deep water or far from the river mouth (Stasiak 2006). 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 unrelated to choice of spawning site or early egg survival (Brown 1969; Brown et al. 1970).

Liard Hot Springs

The habitat of the two hot springs populations differs markedly from cold-water habitats. Liard Hot Springs are the second largest hot springs complex in Canada and form a unique ecosystem. Unlike most other thermal springs in Canada, the Liard Hot Springs do not flow into a nearby river or creek, but into an intricate system of swamps. Vegetation in the hot springs complex 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, Hotwater Physa (*Physella wrighti*) that has been designated as Endangered by COSEWIC (COSEWIC 2008) and is listed as Endangered under Schedule 1 of the *Species at Risk Act* (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 (Jordan and Nathan 1990). Liard Hot Springs Lake Chub occupy a wide range of temperatures (from about 15 to 26ºC).

The two areas occupied by Lake Chub in the Liard Hot Springs complex, Alpha and Delta-Epsilon complexes, have unique habitat characteristics in comparison to cold-water sites and to each other (Figure 3). In the Alpha complex, Lake Chub are found throughout Alpha Swamp, which begins about 150 m downstream of Alpha Pool, and throughout the flooded forest. In the Delta-Epsilon complex Lake Chub inhabit the actual hot pools (Delta and Epsilon), which are probably separate, but may be intermittently connected by beaver activity. 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 are up to two metres deep with large woody debris encrusted in green sponge, and instead of mats of *Chara* sp., the bottom is checkered with patches of filamentous algae and dark organic mud. The water of both areas has near neutral pH (6.8–7.7) and conductivities around 1100 µ siemens cm^{-1}. 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) observed that Lake Chub occupy a wide range of temperatures in both ponds (from about 15 to 26ºC), but they were particularly abundant at 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 appears to decrease considerably in the Liard Hot Springs complex during winter. McPhail (2001) reports that on October 20, 1993 the flooded forests and the edges of Alpha Swamp were frozen but a large shallow pond remained in the swamp near the parking lot although near freezing (1.4°C) and no fish were observed. However, three narrow rivulets crossing under the boardwalk remained. Water temperature in the small channel nearest the parking lot was 10.7°C and contained Lake Chub as did nearby still-water sites with temperatures ranging from 7.8–11.2°C. Temperature in the main (central) rivulet was 12.3°C and in the northern rivulet it was 11.5°C and large numbers of Lake Chub were seen at both sites (McPhail 2001). Between the two channels was a shallow pond (water temperature 6.0°C) that was devoid of fish. It appears that as winter proceeds Lake Chub in sites peripheral to the warm rivulets either move into the rivulets or perish. Consequently, the habitable area available in Alpha Swamp probably contracts in winter.

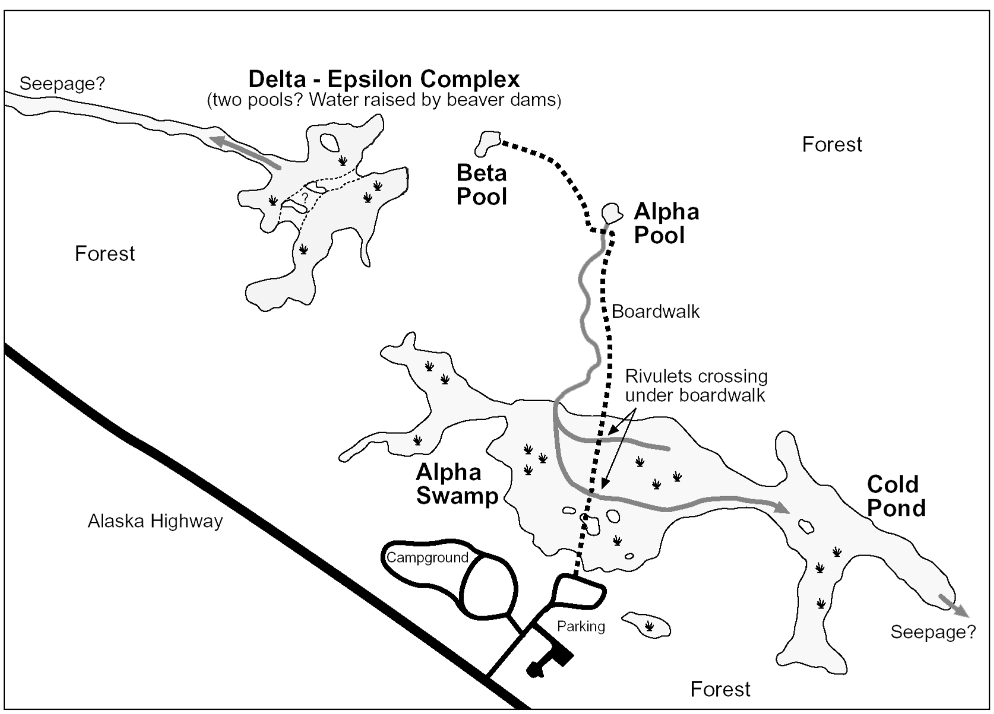

Figure 3. Sketch map of the Liard Hot Springs complex (reproduced from McPhail 2001).

Atlin Warm Springs

The southern Yukon and northwestern British Columbia in the vicinity of Atlin Lake is a tectonically-active region located between two volcanic fields, Surprise Lake and Llangorse, known as the Atlin Volcanic Field (Edwards et al. 2003). It is unknown whether the proximity to volcanism, or simple mantle heating of groundwater generates the warmth of these springs (deBruyn 2019). Atlin Lake is the largest natural lake in British Columbia, with a portion extending into the Yukon. The lake is fed largely by the Llewellyn Glacier, which maintains its temperature between 0–5°C throughout the year, but some bays can reach temperatures of 12°C (Gilbert et al. 2006). The warm springs are about 23 kilometres south-southeast of Atlin, British Columbia and are accessible year-round by a gravel road. They are drained by a series of warm streams and wetlands, before flowing into Warm Bay in Atlin Lake, approximately 850 metres downstream (Figure 4). The Atlin Warm Springs complex is comprised of two separated sections: a western portion that exists on private property, and an eastern portion accessible to the public (deBruyn 2019). The western portion is a single unbranched stream that is used to heat and water greenhouses. It is ditched in several areas, and lacks any large wetlands. The eastern portion is a branching complex of streams, divided by several tufa (limestone precipitate) cascades, and a series of marshy wetlands (Figure 5). The two geothermal areas drain into Warm Bay separately about 290 metres apart making it unlikely that any warm adapted fauna could move between them (deBruyn 2019).

The Atlin Warm Springs are located in a grassy meadow (Figure 6). The main pool has an upwelling spring at one end and gravel substrate covered with filamentous algae. McPhail (2001) visited the pool on September 19, 2000, reporting that the water was warm (21–24°C), the pH was 7.2, and the conductivity was 414 µ siemens cm-1. 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 is completely overgrown with watercress (Nasturtium officinale), and meanders across the meadow, becoming discontinuous after about 1 km. The upper pool was a consistent 26°C throughout the year in 2018, with a maximum 3°C change from day to night (deBruyn 2019). Downstream sections have a minimum water temperature of 11–15°C year round despite surrounding air temperatures averaging between -5 to -15°C from November to March sometimes dropping to -40°C and lower. The region’s water temperature is driven largely by geothermal factors, rather than atmospheric conditions. Water in the upper regions of the springs have small daily swings of roughly two degrees and remain largely steady throughout the year. Further away from the warm springs, ambient air temperature has a larger impact, and the waters cool in the winter (deBruyn 2019).

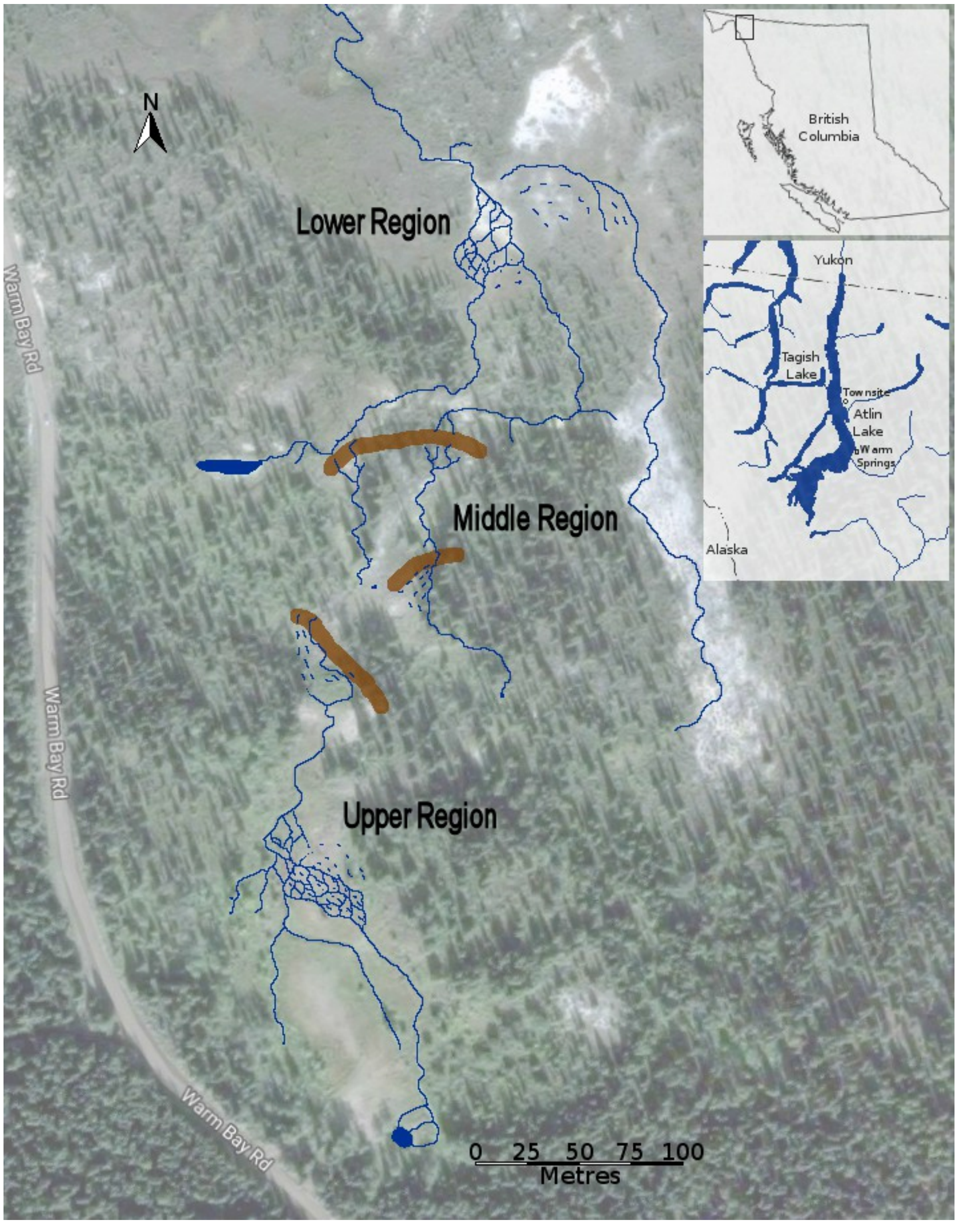

Figure 4. Map of the Atlin Warm Springs. Thin blue lines indicate water, the broad brown lines indicate natural barriers and abrupt changes in elevation that obstruct movement and disrupt surface flow. The top right insets show the position of the warm springs in relation to Atlin Lake and the position of the study area in northwestern British Columbia. The pond at lower left is shown in Figure 6. Satellite Imagery ©2018 DigitalGlobe; Map Data ©2018 Google (reproduced from deBruyn 2019).

Figure 5. Image of a cascade, separating regions of open water in the Atlin Warm Springs complex. Tufa has precipitated over mosses to form hanging pools. This image shows approximately 6 metres of elevation change while there is between 11 and 13 metres of elevation difference between middle and lower regions in Figure 4. Reproduced from deBruyn (2019).

Figure 6. Pond at the head of the east Atlin Warm Springs complex during summer (left, August 2008) and winter (right, January 2009). The pond is about 10 metres wide by 1 metre deep. Photos by E. Taylor (summer) and M. Connor (winter). Reproduced from deBruyn (2019).

The area surrounding the warm springs is typical Canadian boreal forest (Figure 6), consisting of White Spruce (*Picea glauca*), Black Spruce (*Picea mariana*), Lodgepole Pine (*Pinus contorta*) and Subalpine Fir (*Abies labioscarpa*). Deciduous trees and large shrubs include Balsam Poplar (*Populus balsamifera*), Trembling Aspen (*Populus tremuloides*) and a variety of willows (*Salix* spp.). A variety of large and small mammals inhabit the area, most unlikely to predate on Lake Chub (deBruyn 2019). A variety of birds also use the site including Black-capped Chickadees

(*Poecile atricapillus*) and Common Ravens (*Corvus corax*) as year-round occupants, with other passerines and raptors occasionally present (deBruyn 2019).

Amphibians are also found within the warm springs. A population of Western Toads (*Bufo boreas*) believed to be adapted to the warm springs given their reproductive timing relative to nearby cold-water populations is known to occur (Slough and deBruyn 2018) as well as the Wood Frog (*Rana sylvatica*) and Columbia Spotted Frog (*Rana luteiventris*). Western Toad tadpoles were found in the warm springs complex in 2015 by Slough and deBruyn (2018) and likely represent a re-colonization from a nearby population rather than recovery of a remnant warm springs population.

The pools and streams include an abundance of fairy shrimp (Anostraca), leeches (Hirudinea), freshwater snails (Gastropoda) and aquatic beetles (Coleoptera). In addition, deBruyn (2019) reports the existence of a population of Cherry Shrimp (*Neocaridina davidi* var. *red*), native to the island of Taiwan, apparently introduced in late 2015 that has rapidly invaded the warmest regions of the springs (Figure 7).

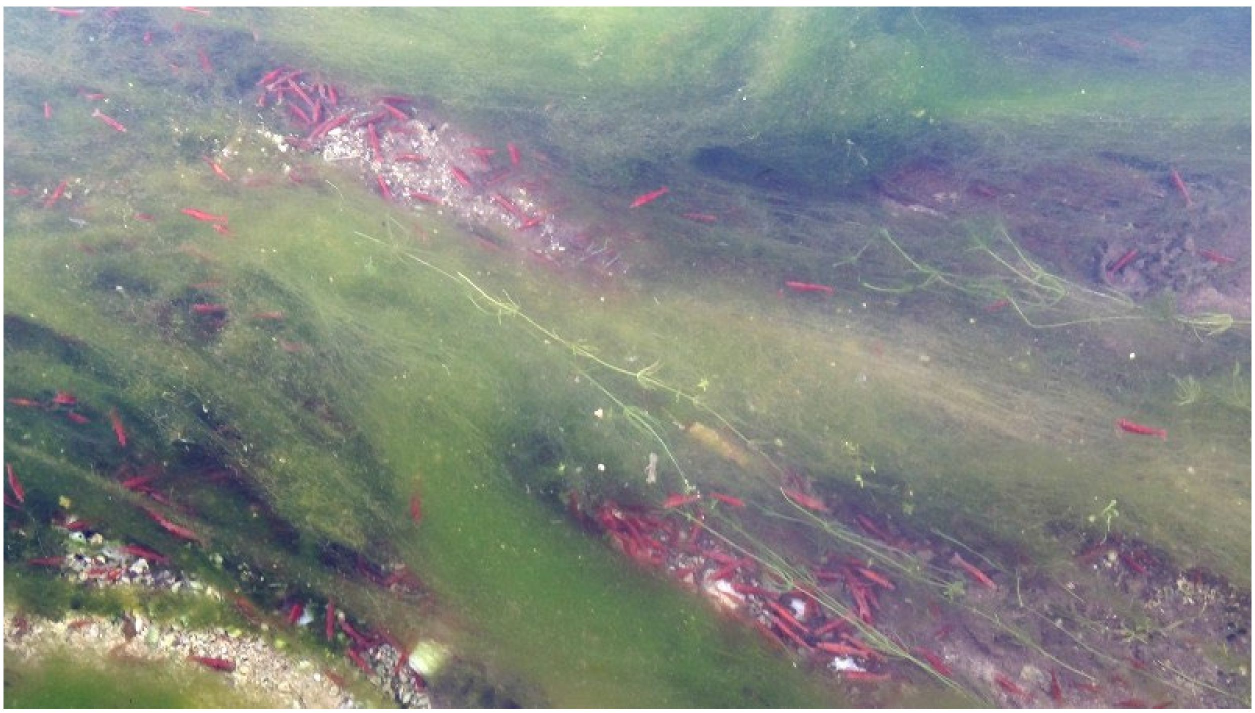

Figure 7. Cherry shrimp (N. davidi var. red) clustering in the algae and stream bottom of the Atlin Warm Springs complex, May 20, 2016. Reproduced from deBruyn (2019).

Lake Chub is the only native fish present in the eastern portion of the warm springs. Common Goldfish (*Carassius auratus*) has been introduced into the western portion of the warm springs within the past decade.

Element 5: Provide information on the spatial extent of the areas in Lake Chub's (Liard Hot Springs and Atlin Warm Springs populations) distribution that are likely to have these habitat properties

Similar areas of volcanic and geothermal activity are rare within the known range of Lake Chub. Reports of Lake Chub being associated with three other upper Liard Hot Springs at Deer River, Crooked Lake and Portage Brule, remain unconfirmed (COSEWIC 2018). It is unclear if the Lake Chub population at the Deer River thermal springs is significant and discrete based on lack of information on thermal behaviour and physiology and connectedness with the Deer River (Greg Wilson, BC Ministry of Environment, Victoria, BC 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 but this is unconfirmed. Thus, it appears that these two populations represent the only known viable populations of thermally associated Lake Chub in Canada.

Liard Hot Springs

The Liard Hot Springs is a complex of springs, pools, swamps, and rivulets (Figure 3). Alpha Hot Pool has been developed for bathing as part of the Liard Hot Springs Provincial Park. Lake Chub are associated with the Liard Hot Spring's Alpha and Delta-Epsilon complexes. The Liard Hot Springs complex has no connections to other streams (Figure 8); its outflow is contained entirely within the adjacent swamps and flooded forest (McPhail 2001; BC Parks 2003). The index of the area of occupancy is 12.0 km^2.

Figure 8. Satellite image of the Liard Hot Springs complex. Alpha Pool is in the upper right corner of the image. See Figure 3 for detailed description. Reproduced from COSEWIC (2018).

Atlin Warm Springs

The Atlin Warm Springs DU consists of an oval main pool, estimated at roughly 20 m long by 6 m wide, drained by four rivulets that combine to form an outlet stream (McPhail 2001). Lake Chub inhabit the pool but are particularly abundant in the outlet stream. The size of the main pool was estimated at 10 m wide and 1 m deep (Figure 5) by deBruyn (2019) suggesting a possible reduction in size and rate of inflow. The area of occupancy and extent of occurrence for the Atlin Warm Springs Lake Chub DU is 4.0 km^2 (COSEWIC 2018). The area of occupancy was estimated similarly as 3,602 m^2, or 0.004 km^2 by deBruyn (2019). deBruyn (2019) divided it into an upper region of 1,983 m^2, a middle's region of 398 m^2, and a lower region of 1,222 m^2. The apparent small size of the middle region was more pronounced in terms of area than volume because the upper and lower regions both have sizeable areas of very shallow wetland. The Atlin Warm Springs complex also has no connections to other streams; its outflow is contained entirely within the adjacent meadows terminating at the outflow into Warm Bay in Atlin Lake, a linear extent of about one kilometre.

Figure 9. Satellite image of the Atlin Warm Springs complex. Bathing Pool is in the lower left corner of the image and Atlin Lake is in the upper left corner. See Figure 4 for detailed description. Satellite Imagery ©2018 DigitalGlobe; Map Data ©2018 Google.

Element 6: Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.

Lake Chub in the two populations considered here are isolated populations with limited opportunity to move elsewhere due to physical habitat constraints but likely more importantly due to thermal limitations to which they have become adapted.

Liard Hot Springs

The Liard Hot Springs, is a complex (Figure 3) of thermal springs, pools, swamps, and rivulets contained within Liard Hot Springs Provincial Park. If there is a passable connection, the hot springs complex may not be isolated from immigration (and, thus, gene flow) from the mainstem Liard River (McPhail 2001). The closest stream that may connect the hot springs complex and the Liard River is an unnamed stream that enters the river about 200 m east of the Liard Crossing Bridge. McPhail (2001) noted the water temperature at 6.7°C, the pH 8.19, and the conductivity 859 µ siemens cm^{-1} on September 15, 2000. No Lake Chub were found either in the stream or the mainstem Liard River near the stream mouth. Similarly, in Hoole Creek (located on the south bank of the Liard across from the Provincial Park) the water temperature was 6.1°C, the pH 8.25, and the conductivity 359 µ siemens cm^{-1} on the same day. In contrast, the outflow from Alpha Pool where it passes under the boardwalk was 18.1°C, the pH 7.74, and the conductivity 1131 µ siemens cm^{-1} (McPhail 2001). Therefore, although the unnamed stream may get seepage from the thermal complex, stream temperature and pH are comparable to Hoole Creek, and it appears that there is no direct connection between the stream and the hot springs. Another possible connection is at the southwestern edge of the complex (Figure 3). McPhail (2001) reports that on September 17, 2000 the outflow from Delta and Epsilon thermal pools is southwest towards the Alaska Highway and aerial photos suggested the possibility of flow under the highway. The next day, the area was found to be boggy but there was no evidence of flowing water, thermal activity, or fish (McPhail 2001). Although there may be seepage in this area, inspection of both potential outflows indicated that at present Lake Chub in the hot springs complex are completely isolated from the Liard River.

Within the Liard Hot Springs, the Alpha Pool Complex consists of a large pool that is developed as public bathing site. The temperature varies but usually is about 36°C at the outlet dam. Further downstream the stream runs through a forested swamp and the water cools. The substrate is soft calcareous mud and the stream flows over, and among, dense mats of *Chara* sp. (McPhail 2001). On September 16, 2000 approximately 100 m below the dam the water temperature was 30°C. About 150 m downstream of the dam water entered a tufa-ponded swamp and by 300 m the temperature was down to 20°C (McPhail 2001). The stream splits into two rivulets before it crosses beneath the boardwalk to Alpha Pool. The largest rivulet is approximately in the middle of the swamp and the smaller rivulet is about 30 m to the north. Lake Chub were abundant in both rivulets and the water temperature in both channels was about 18°C (McPhail 2001). Approximately 200 m downstream of the boardwalk the rivulets enter an open area, referred to as the non-thermal Cold Pond (Reid 1978), and water temperatures had dropped to 10–12°C. Lake Chub were seen throughout the tufa swamp and in flooded sections of the forest as far as the campground. In the swamp and flooded forest areas the water temperatures ranged from 18–26°C (McPhail 2001). No lake chub were observed at water temperatures below 14 or above 27°C.

The other major thermal complex in the Liard Hot Spring is the Delta-Epsilon Pool Complex, located about 100 m west of Beta Pool (Figure 3). It consists of two thermal pools (Delta and Epsilon) but it is unclear whether the two pools are completely separate (McPhail. 2001). Beaver activity in the area can raise water levels so there may be intermittent connections between the two pools. Delta Pool was 23°C, the pH was 6.8, and the conductivity was 1090 siemens cm^{-1} when visited in September, 2000 (McPhail 2001). Epsilon Pool was 25°C, the pH was 6.85, and the conductivity was 1125 µ siemens cm^{-1}. Although the Delta-Epsilon complex is a very different habitat from the Alpha complex, Lake Chub are abundant in both complexes (McPhail 2001). Instead of the small shallow rivulets and swamps with dense mats of *Chara* sp. characteristic of the Alpha complex, the Delta-Epsilon complex consists of two large pools that may be up to two metres in depth. Both pools contain large woody debris (trees fallen by beavers and some dead standing trees) that is encrusted with a green sponge. Both pools contain areas of thermal activity with steep temperature gradients. The temperature near the thermal vent was 34°C in Epsilon Pool while fifteen metres to the east the temperature was 27°C and within another 15 metres it had dropped to 20°C. At this cool site the pH was 7.05 but the conductivity was unchanged (1125 µ siemens cm^{-1}). No Lake Chub were observed at or near the thermal vent, one at the 27°C site, and fish were abundant at sites with water temperatures between 23 and 25°C (McPhail 2001). Lake Chub were also present, but seemingly less abundant, at the 20°C site.

Atlin Warm Springs

The Atlin Warm Springs is in a large grassy meadow about 900 m south and 50 m east of the Warm Bay Recreation Site in Atlin Lake. It is possible that if outflows from the warm spring increased drastically (e.g., due to extreme climate or hydrological conditions) a temporary connection to Atlin Lake might form. Atlin Lake also contains cold-water Lake Chub (FISS 2004) and the possibility exists that such a connection could allow Lake Chub movement in both directions between Atlin Lake and the Atlin Warm Springs. The main pool feeding the warm springs is about one kilometre from Atlin Lake. It is roughly oval shaped with an upwelling spring at one end of the pool (Figure 4). The area immediately downstream from the warm springs pool, where geothermal water emerged from the ground, was named the 'Upper Region' in deBruyn’s (2019) study. It is comprised of several streams that emerge hot from the ground or out of pools, and pass through an open marsh before coalescing into a single stream, which then reaches the first cascade. Three separate areas were defined by deBruyn (2019) that were separated by structures that he refers to as cascades, or 'tufa barrages' (Profe et al. 2016). Each cascade is a series of calcified steps composed of tufa limestone, forming a series of terraced pools (Figure 4). Steady flow proceeds through narrow waterfalls or underground between these pools. No visible connection was evident between the different regions, suggesting that they formed natural barriers impeding Lake Chub’s ability to disperse. The 'Middle Region' (Figure 4) was initially comprised of two connected streams separated from the upper region by 20 metres of tufa-encrusted moss and dry land. Between the 2016 and 2017 the connecting stream dried, leaving the area as two disconnected streams that are narrow and shallow with a few deeper sections in the upper reaches of the eastern stream that are heavily forested (deBruyn 2019).

The streams in this area are dynamic, with rerouting of the middle region's streams in the winter of 2016 and 2017 likely attributable to the soft, marshy ground, which is composed largely of spongy moss (deBruyn 2019). Falling logs, seasonal freezing and human or animal activity can easily reroute streams. The largest area, called the 'Lower Region' (Figure 4), and includes the widest, deepest and coolest parts of the stream. Its two main stems both begin in forested areas: the eastern branch begins below the second cascade, while the western branch begins at the western pond, site of Western Toad reproduction (see Slough and deBruyn 2018). The branches continue downstream, draining into an open marshland, coalescing into a single stream that drains through a culvert under Warm Bay Road into Warm Bay, in Atlin Lake (deBruyn 2019). The outlet stream where it entered Warm Bay was 12°C on September 19, 2000 (McPhail 2001). The outlet stream above the lake has been checked for Lake Chub without success (McPhail 2001; deBruyn 2019).

Element 7: Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence

SARA defines a residence as "a dwelling place, such as a den, nest or other similar area or place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating" (S.C. 2002 c29).

The residence must support a life cycle function, there must be an element of investment in the creation or modification of the structure, and it must be occupied by one or more individuals. Lake Chub are broadcast spawners and they do not modify their environment for the purpose of breeding, rearing, and staging. As a result the concept of residence does not apply.

Threats and Limiting Factors to the Survival and Recovery of Lake Chub (Liard Hot Springs and Atlin Warm Springs populations)

Element 8: Assess and prioritize the threats to the survival and recovery of the Lake Chub (Liard Hot Springs and Atlin Warm Springs populations)

The main threats to cold-water Lake Chub are those which impact 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 have the potential to 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 impacted populations in some systems (Stasiak 2006). Although not as extensively studied, similar threats would be expected for the thermal springs populations.

Liard Hot Springs DU

The three main threats identified for Liard Hot Springs Lake Chub in the COSEWIC threats calculations (Appendix 1) are invasions by non-native/alien species or diseases, domestic and urban wastewater, and garbage and solid waste pollution (COSEWIC 2018). The threat from invasive species was rated as large to small in scope impacting 1 to 70 percent of the population and expected to pose a serious to slight threat resulting in a mortality of 1 to 70 percent of the population over the next decade. The threat from domestic and urban wastewater was rated as large in scope affecting 31 to 70 percent of the population with an unknown impact over the next decade but continuing. The threat from domestic and solid waste was rated as large, affecting 31 to 70 percent of the population with a negligible impact resulting in a mortality rate of less than 1 percent over the next decade and continuing.

Invasive non-native/alien species/diseases

Introduction of a non-native species to the Laird Hot Springs complex could have severe impacts, depending on the species, including predation, competition, introgression, disease and habitat alteration. The extinction of the Banff Longnose Dace (*Rhinicthys cataractae smithi*) from the hot springs at Banff National Park, Banff, Alberta (Lanteigne 1987) occurred after the deliberate introduction of Mosquitofish (*Gambusia affinis*) in the 1920s, followed by various tropical fish, that created competition and predation of the eggs and young dace. Subsequent hybridization with Eastern Longnose Dace (*Rhinichthys cataractae*) resulted in its disappearance by the late 1980s. Thermal environments are naturally fragile ecosystems that could suffer irreversible impacts because of their limited size and reliance on a constant replenishment of spring-fed water. An introduction of Common Goldfish (*Carassius auratus*) or related Common Carp/Koi (*Cyprinus carpio*) could have significant impacts on such an environment and the single species inhabitants. These cyprinids are notorious for disturbing habitat and increasing turbidity, making feeding for a visual forager like Lake Chub difficult. 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 (*Lepomis macrochirus*), Black Crappie (*Pomoxis nigromaculatus*), Yellow Perch (*Perca flavescens*), Smallmouth Bass (*Micropterus dolomieu*) and Largemouth Bass (*M. salmoides*)) that overlap in habitat use of lakes (i.e., littoral zone) with Lake Chub could decimate their populations if 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 be amenable for these predatory species, some of which are usually limited to more temperate conditions than exist in northern watersheds. Non-native fish can also introduce pathogens to native 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 was illegally introduced into the Atlin Warm springs (see below).

Domestic and Urban Wastewater and Garbage and Solid Waste

Liard Hot Springs Provincial Park is a popular stop on the Alaska highway and the busiest park in northern BC (Jordan and Nathan 1990). The 53 campsites and day use parking lot are often filled past capacity throughout the summer months. The heavy use of the park, and the isolation and limited size of the Lake Chub's unique thermal environment all increase the potential threat of contaminants to Liard Hot Springs Lake Chub. The use of soap and shampoo is prohibited in the hot springs, but bathers are not monitored by park staff and may introduce contaminants into the water. Deleterious substances that may be introduced to the hot springs ecosystem by visitors include lantern fuel, suntan lotions, insect repellant, and bath oils. The amount of contaminants added to the water on an ongoing basis is likely insignificant relative to the total volume of the hot springs complex, and any impact should be reduced through dilution. Recent testing for aggregate organics by BC government researchers found trace to 2.3 mg/L of contaminants in the hot springs and there was no evidence of tricosan, an antimicrobial chemical common in shampoos, deodorants, and toothpaste (Greg Wilson, BC Ministry of Environment, Victoria, BC 2018). The increased use of the park over time brings the threat of greater littering or dumping of human garbage along the boardwalk or the bathing pool and parking area. The disintegration of litter and leaching of chemicals into the waters of the hot springs could negatively impact the Lake Chub habitat. The Master Plan for the park (Jordan and Nathan 1990) indicates that no significant increases in development will occur within the park (i.e., no additional parking). However, new development of private campgrounds and accommodation outside the park will continue to increase recreational demands on the hot springs.

Atlin Warm Springs DU

The main threats identified for Atlin Warm Springs Lake Chub in the COSEWIC threats calculations are similar to those identified for the Liard Hot Springs (Appendix 2): invasions by non-native/alien species or diseases, domestic and urban wastewater, and garbage and solid waste pollution. The threat from invasive species was rated as large to small in scope affecting 1 to 70 percent of the population and expected to pose a serious to slight impact resulting in a mortality of 1 to 70 percent of the population over the next decade and continuing. The threat from domestic and urban wastewater was rated as large in scope affecting 31 to 70 of the population with an unknown impact over the next decade and continuing. The threat from domestic and solid waste was rated as large affecting 31 to 70 percent of the population with a slight impact resulting in a mortality rate 1 to 10 percent over more than the next decade and continuing. Scientific collections of Lake Chub with non-lethal sampling was rated as negligible with a restricted scope affecting 11 to 30 percent of the population with a negligible impact resulting in mortality of less than 1 percent of the population within the next decade. An unknown limiting factor is that of earthquakes, which are common in the area and could be pervasive in scope affecting 71 to 100 percent of the population with an extreme impact potentially causing mortality of 71 to 100 percent of the population. The timing was rated as low, possibly occurring in the long term, more than a decade in the future.

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 for the Liard Hot Springs. In 2015, non-native Cherry Shrimp, normally an Asian aquarium species, was first noted in the Atlin Warm Springs and has become an important food item for Lake Chub in the warmest upper region of the springs (deBruyn 2019). The long-term impact of this introduction is unknown. Additional concern exists for this DU regarding introduction of other aquarium species, particularly the Common Goldfish, or Common Carp/Koi or other warm-water non-native species. Goldfish have been found in the lower reaches of the western portion of the warm springs that exist on private property. The local First Nation has made some effort to eradicate them but the efficacy of this effort is unknown. Potential introduction of turtles into the warm springs is a concern although Lake Chub co-occur with them in many non-thermal environments.

Domestic and Urban Wastewater and Garbage and Solid Waste

The Atlin Warm Springs is in frequent use for bathing by both tourists and residents of the nearby town of Atlin. The same issues around the introduction of contaminants associated with insect repellants, suntan lotion, shampoo, and soaps exist as in the Liard Hot Springs although the potential impact may be larger given the apparently smaller water volume for dilution. Similarly, increased use of the warm springs over time brings the threat of greater littering or dumping of human garbage in the vicinity of the bathing pool. The disintegration of litter and leaching of chemicals into the waters of the warm springs could negatively impact the Lake Chub habitat.

Element 9: Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4–5 and provide information on the extent and consequences of these activities

Human development has had some negative effects on the habitat of Liard Hot Springs Lake Chub. The first boardwalks 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 (Figure 8) is thought to have killed a large number of Lake Chub (perhaps hundreds) but only a relatively small proportion of the total population (COSEWIC 2018, Samford and Taylor, 2001). There have been additional changes to the Alpha pool including the construction of a small dam at the outlet of the pool and a series of constructions of bathing facilities at the pool site, the most recent in November, 2012.

The Atlin Warm Springs have also been impacted by human activities. Apparently excavators have occasionally been used to maintain the quality of the main pool for bathing (COSEWIC 2018, Samford and Taylor 2004.). Although there are reports that the temperature of the springs was lowered by excavation conducted in the late 1980s (COSEWIC 2018, Samford and Taylor 2004), when the springs were visited in 2000, they were still warm (21–25ºC) and intact (McPhail 2001). deBruyn (2019) also reports that the upper pool maintains a consistent 26ºC throughout the year. It is unlikely that future maintenance excavation will continue, and no impacts were evident in visits from 2014 to 2017 .

It is anticipated that oil and gas development in northern British Columbia will continue to increase. The concern is that deep well drilling and production via horizontal drilling and/or hydraulic fracturing could: 1) contaminate source water with fracking fluids, 2) disrupt current thermal spring flow volume (and/or temperature), or 3) increase seismic activity which could also disrupt or change the underground water flow patterns (COSEWIC 2018). However, oil and gas development is not currently occurring near either of these two thermal springs.

Element 10: Assess any natural factors that will limit the survival and recovery of the Lake Chub (Liard Hot Springs and Atlin Warm Springs populations)

The critical natural factors that will limit the survival and recovery of Lake Chub (Liard Hot Springs and Atlin Warm Springs populations) are habitat loss and water temperature. Both thermal complexes that support Lake Chub are of limited extent and provide a unique habitat that supports the survival of these fish that have acclimatized to an unusually warm environment for the species. Maintenance of the currently available habitat is critical to the survival of these populations. Similarly, the continuing supply of hot water to both populations is critical to maintaining the habitat required for the survival and recovery of the Lake Chub in both thermal complexes and any activities that might disrupt the thermal flows could compromise their survival.

The other natural factor that could limit the survival and recovery of Lake Chub is predation. While there is no evidence of other fish species present in the Laird Hot Spring or Atlin Warm Springs, it is a factor in other cold-water Lake Chub populations. Scott and Crossman (1973) report several species of fishes feeding on cold-water Lake Chub including Northern Pike (*Esox lucius*), Lake Trout (*Salvelinus namycush*), Burbot (*Lota lota*), and Walleye (*Sander vitreum*). Brown (1969) found no evidence of Lake Chub in many predatory fish stomachs examined in Lac La Ronge, Saskatchewan, although alternative prey items were present. 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. Stasiak (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, and amphibians also occur in small ponds and streams where Lake Chub are found and are likely predators (COSEWCI 2018). Brown et al. (1970) also report that spawning Lake Chub frequently cannibalized their eggs.

Liard Hot Springs

At present, there is no evidence of other fish species in the Liard River Hot Springs that would predate or compete with Lake Chub (Craig and Bruce 1983; McPhail 2001). 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) in cold-water environments. Interestingly, 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 mud until their stomachs fill to distension and these contained insect parts, pea clams, and bits of snail shells (McPhail 2001). The parasitic flatworm larvae (*Neascus* sp.) has infected a significant proportion of the Liard Hot Springs Lake Chub causing Black Spot disease, apparently resulting in higher mortality of males (McPhail 2001). The intermediate host in the life cycle is typically a fish-eating bird or snail. Therefore, Hotwater Physa, an endangered snail present in the hot springs, may play a role in this life-cycle.

Atlin Warm Springs

At present, there is no evidence of other fish species in the Atlin Warm Springs that would predate or compete with Lake Chub (deBruyn 2019). However, Cherry Shrimp *(Neocaridina davidi)* was first observed in the Atlin Warm Springs in 2015. It is an invasive species that has grown exponentially and has effectively colonized the upper portion of the warm springs. It appears to have become an important food item for the Lake Chub in this population. Indications are that it is limited to water temperatures above 20ºC and so has not infiltrated the cooler lower reaches of the warm springs (deBruyn 2019).

Toads and frogs also occur in the warm springs and could potentially prey on Lake Chub, particularly the larval and juvenile forms.

Element 11: Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species. List the possible benefits and disadvantages to the target species and other co-occurring species that may occur if the threats are abated. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps

The two main threats to Lake Chub in both populations are the introduction of non-native invasive species and the introduction of contaminants into the ecosystem. The abatement of the threat of species introductions is unlikely and more of a concern for Atlin Warm Springs given its proximity to human settlement. In any event, abatement would not have a directly beneficial effect on the species in either system since both appear to be at or near carrying capacity. Prevention of this threat could require an outright ban on the sale of exotic aquarium species in Canada and greater diligence in monitoring attempts to introduce native or non-native species into new environments. Other options include greater education on the threat of introduced species and early detection of invasive species.

The existing impact of contaminants in either thermal environment is unknown. Reducing or eliminating the introduction of contaminants into these environments would presumably benefit the Lake Chub populations if they have been impacted but the extent to which this would occur is unknown.

Although Hotwater Physa are SARA listed and only found at Liard Hotsprings there is no known monitoring program in place for any taxa either at Liard Hotspring or Atlin Warm Spings.

Recovery Targets

Element 12: Propose candidate abundance and distribution target(s) for recovery

Liard Hot Springs

Efforts should be undertaken to ensure that the population does not decrease from its current population distribution or size. Further exploratory surveys could be undertaken to confirm distribution and abundance. The distribution target is recommended as the known existing range within the Liard Hot Springs complex. COSEWIC (2018) indicates that abundance may be in the thousands but is based on cursory visual assessment and Lake Chub are known to be cryptic so abundance could be substantially higher. Further, McPhail (2001) suggests that there may be three separate populations extant in the hot springs that would require separate distribution and abundance targets.

Atlin Warm Springs

Lake Chub are widely distributed throughout the warm springs complex being found in all three disjunct areas identified by deBruyn (2019). A distribution target would be to maintain broad distribution of fish throughout all three sites. A mark-recapture study conducted throughout 2016 and 2017 indicates an abundance of 1000 to 2000 individuals larger than 3 cm fork length in the entire complex while a concurrent visual survey suggested that abundance could be slightly higher (deBruyn 2019). The tagging study also confirmed that there is relatively little movement of individual Lake Chub of more than 25 m supporting the existence of three separate populations within the warm spring for which separate abundance and distribution targets are needed.

Efforts should be undertaken to ensure that the population does not decrease from its current population distribution or size within the Atlin Warm Springs complex. Further exploratory surveys could be undertaken to confirm distribution. However, until distribution is confirmed, the target is recommended as the known existing range within the Atlin Warm Springs complex.

Element 13: Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current Lake Chub (Liard Hot Springs and Atlin Warm Springs populations) population dynamics parameters

Liard Hot Springs

No quantitative abundance information exists, therefore numerical targets and trajectories cannot be provided.

Atlin Warm Springs

The Lake Chub population is assumed to be at or near carrying capacity for the available thermal environment and given status quo mortality and productivity it should remain stable at the currently estimated abundance of 1000 to 2000 individuals greater than 3 cm.

Element 14: Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12

Liard Hot Springs

Lake Chub populations in the hot spring complex are believed to be at or near carrying capacity for the thermal environment, but further work would need to be conducted to confirm. The available habitat should continue to meet the demands of the species at the current level of abundance unless there are unexpected changes in the flow or temperature of the springs feeding into the system.

Atlin Warm Springs

Lake Chub populations in the warm spring complex are believed to be at or near carrying capacity for the thermal environment, but further work would need to be conducted to confirm. The available habitat should continue to meet the demands of the species at the current level of abundance unless there are unexpected changes in the flow or temperature of the springs feeding into the system. At present, the invasive Cherry Shrimp have colonized only the upper portion of the warm springs and appear to provide a novel food item for Lake Chub (deBruyn 2019). The impacts of this introduction to the ecosystem, both positive and negative, are unclear. As a source of food for Lake Chub, Cherry Shrimp could increase reproductive capacity resulting in greater abundance; conversely, by their consumptive practices, Cherry Shrimp might reduce the overall productivity of the system and thereby reduce the carrying capacity and total number of Lake Chub the system can support in the longer term.

Element 15: Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters

Given the paucity of data on biological traits, population dynamics and abundance, population trajectories and probabilities of meeting different targets cannot be provided for either DU. A general assumption however is that existing threats and habitat limitation have been present for multiple generations of Lake Chub and the species continues to survive in these thermal environments. However, there is significant uncertainty associated with this assumption. Targeted research on life-history parameters, abundance, and distribution would greatly increase the likelihood of being able to provide trajectories to different quantitative targets.

Scenarios for Mitigation of Threats and Alternatives to Activities

Element 16: Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10)

There are limited mitigation measures that directly address the threats other than increased monitoring of the pools' use by bathers, prevention, education and early detection of invasive species. A better understanding of the basic biology of the species and the potential impacts of pollutants from the introduction of various contaminants into the two thermal springs may also aid in decision making. At present, these potential effects are unknown. Additionally, a better understanding of the potential interactions between invasive species and Lake Chub would aid in future management.

Element 17: Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15)

Collecting additional abiotic data, biological, and distribution information that could aid in the determination of the factors regulating population abundance and individual survival is recommended.

For example:

- Monitor the temperature gradients in both the Liard Hot Springs and Atlin Warm Springs in relation to the Lake Chub distribution to clarify the extent of viable habitat for the species in each environment. Monitoring should occur both in the summer and winter as McPhail (2001) noted an apparent reduction in the available habitat in the Liard Hot Springs in the late fall.
- Conduct surveys of the Lake Chub throughout the Liard Hot Springs to clarify the distribution and extent of Black Spot disease and its possible impact on the mortality of male and female Lake Chub.
- Monitor the distribution of Cherry Shrimp in the Atlin Warm Springs to evaluate the rate of population expansion. Assess the contribution of Cherry Shrimp to the diet and growth of Lake Chub in the upper section of the habitat relative to other areas to understand if it poses a threat or is enhancing the population.
- Conduct genetic surveys in both thermal springs to clarify whether the populations contain distinct sub-populations or the extent of interaction among the habitat subareas.

- Conduct a mark-recapture or other census study of the Liard Hot Springs to determine baseline population size for assessing future population trajectory. Repeat the mark-recapture or other census study in the Atlin Warm Springs to assess the trend in abundance in this population.
- Monitor the size and age distribution of Lake Chub in both thermal environments to determine growth and mortality rates for projections of population recovery.

Element 18: If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets

It is presumed that both Liard Hot Springs and Atlin Warm Springs Lake Chub populations are at or near their carrying capacities within the available habitat. It is unknown if the creation of additional pool habitat within either DU would lead to increased population abundance. Similarly, introduction of Cherry Shrimp into the Atlin Warm Springs has provided a new food source for Lake Chub, but whether this has increased or negatively affected overall population productivity remains unknown. Eradication of Cherry Shrimp from the warm springs may not be feasible without unintentional negative impact on this population.

Element 19: Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17

Given the paucity of data on biological traits, population dynamics and abundance, population trajectories and probabilities of meeting different targets cannot be provided.

Element 20: Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values

Given the paucity of data on biological traits, population dynamics and abundance, population trajectories and probabilities of meeting different targets cannot be provided.

Element 21: Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process

Given the paucity of data on biological traits, population dynamics and abundance, it is not possible to recommend values for population productivity or mortality rates.

Allowable Harm Assessment

Element 22: Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery

No quantitative advice can be provided at this time on allowable harm to Lake Chub (Liard Hot Springs and Atlin Warm Springs populations). Existing activities, although apparently deleterious, do not appear to be affecting survival of existing populations given the species' ongoing presence. Directed harm from scientific sampling should be undertaken in a coordinated fashion such that the least number of animals are taken while ensuring that questions pertaining to population levels can be addressed.

Conclusions

To support implementation of the *Species at Risk Act* (SARA) Fisheries and Oceans Canada (DFO) develops a Recovery Potential Assessment (RPA) to provide information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery.

Liard Hot Springs and Atlin Warm Springs designatable units (DUs) populations of Lake Chub (*Couesius plumbeus*) were assessed as Threatened by COSEWIC in the fall of 2018 (COSEWIC 2018). Although Lake Chub are the most widespread minnow in North America (McPhail 2007), the Liard Hot Springs and Atlin Warm Springs populations are confined to two unique thermal spring environments in northern British Columbia (McPhail 2007). Although very little is known about these two populations, existing activities, although apparently deleterious, do not appear to be affecting survival of existing populations given the species' ongoing presence.

This RPA provides up-to-date information and discusses associated uncertainties of the 22 elements listed in the Terms of Reference for this Science Response Process. However, no quantitative advice can be provided at this time on a number of elements, including biological traits, population dynamics and abundance, population trajectories, probabilities of meeting different targets and allowable harm. Therefore, it is recommended to conduct additional studies to address these knowledge gaps.

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December 17, 2020

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Appendix 1

Table 1. Threats to the survival of Lake Chub in the Liard Hot Springs identified in the COSEWIC (2018) status review. Only threats that are anticipated to affect the population within ten years or three generations are rated. Table adapted from COSEWIC 2018, and threats which were not assessed, were removed. See COSEWIC 2018 for full details.

THREATS ASSESSMENT WORKSHEET

Species Name	Lake Chub - Liard Hot Springs populations
Date	2018-01-16
Assessors	Jake Schweigert (report 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 Angele Cyr (COSEWIC Secretariat).

Overall Threat Impact

		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

Threats Calculator Table

Threat		Impact (calculated)		Scope (next 10 Yrs.)	Severity (10 Yrs. or 3 Gen.)	Timing	Comments
1	Residential & commercial development	-	-	-	-	-	-
1.3	Tourism & recreation areas	-	-	-	-	-	-
3	Energy production & mining	-	-	-	-	-	-

Threat		Impact (calculated)		Scope (next 10 Yrs.)	Severity (10 Yrs. or 3 Gen.)	Timing	Comments
3.1	Oil & gas drilling		-	-	-	-	-
5	Biological resource use	-	Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs./3 gen.)	-
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
6.3	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)	-
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 may not 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	-

Threat		Impact (calculated)		Scope (next 10 Yrs.)	Severity (10 Yrs. or 3 Gen.)	Timing	Comments
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
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.
9.4	Garbage & solid waste	-	Negligible	Large (31-70%)	Negligible (<1%)	High (Continuing)	some garbage but it is picked up so not persistent
10	Geological events	-	-	-	-	-	-
10.2	Earthquakes/tsunamis	-	-	-	-	-	NA - not a high risk earthquake zone.

Appendix 2

Table 2. Threats to the survival of Lake Chub in the Atlin Warm Springs modified from the COSEWIC (2018) status review. Only threats that are anticipated to affect the population within ten years or three generations are rated. Table adapted from COSEWIC 2018, and threats which were not assessed, were removed. See COSEWIC 2018 for full details.

THREATS ASSESSMENT WORKSHEET

Species Name	Lake Chub - Atlin Warm Springs populations
Date	2018-01-16
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 Angele Cyr (COSEWIC Secretariat).

Overall Threat Impact

		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

Threats Calculator Table

Threat		Impact (calculated)		Scope (next 10 Yrs.)	Severity (10 Yrs. or 3 Gen.)	Timing	Comments
1	Residential & commercial development	-	-	-	-	-	-
1.3	Tourism & recreation areas	-	-	-	-	-	Unknown but near enough to Atlin that development potential exists
3	Energy production & mining	-	Not Calculated (outside assessment timeframe)	Unknown	Unknown	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
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.
5	Biological resource use	-	Negligible	Negligible (<1%)	Negligible (<1%)	Moderate (Possibly in the short term, < 10 yrs./3 gen)	-
5.3	Logging & wood harvesting	-	-	-	-	-	NA
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)	-
6.1	Recreational activities	-	Negligible	Restricted - Small (1-30%)	Negligible (<1%)	High (Continuing)	low probability of encounter
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	-	Negligible (<1%)	Restricted (11-30%)	Negligible (<1%)	High (Continuing)	Dredging for swimming Atlin Warm Springs have occasionally been excavated to maintain the quality of the main pool for bathing (COSEWIC 2018). It is expected that maintenance excavation activity will continue and poses an ongoing threat to the Lake Chub population at that site (COSEWIC 2018). On the other hand, dredging may have some positive effects by maintaining pools that might otherwise silt in and reduce the

Threat		Impact (calculated)		Scope (next 10 Yrs.)	Severity (10 Yrs. or 3 Gen.)	Timing	Comments
							available Lake Chub habitat (COSEWIC 2018). The threat was rated as negligible because of uncertainty in timing over the next ten years (COSEWIC 2018). The threat is ongoing but likely to impact only a small portion of the population (COSEWIC 2018)
8	Invasive & other problematic species & genes	B D	High - Low	Large - Small (1-70%)	Serious - Slight (1-70%)	High - Low	-
8.1	Invasive non-native/alien species/diseases	B D	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	-	-	-	-	-	-
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.
9.4	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
10	Geological events	-	Not Calculated (outside assessment timeframe)	Pervasive (71-100%)	Extreme (71-100%)	Low (Possibly in the long term, >10 yrs./3 gen)	-
10.2	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.

This Report is Available from the:

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ISSN 1919-3769

Correct Citation for this Publication:

DFO. 2021. Recovery Potential Assessment for Lake Chub (*Couesius plumbeus*), Liard Hot Springs and Atlin Warm Springs Populations. DFO Can. Sci. Advis. Sec. Sci. Resp. 2021/008.

Aussi disponible en français :

MPO. 2021. Évaluation du potentiel de rétablissement du méné de lac (Couesius plumbeus), populations des sources thermales de la Liard et des sources thermales d'Atlin. Secr. can. de consult. sci. du MPO. Rép. des Sci. 2021/008.