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Pacific Region

Canadian Science Advisory Secretariat
Science Response 2023/025

EFFECT OF COWICHAN LAKE WATER MANAGEMENT ON VANCOUVER LAMPREY IN BRITISH COLUMBIA AND IDENTIFICATION OF POSSIBLE ENHANCEMENT OPPORTUNITIES

Context

Vancouver Lamprey (also known as Cowichan Lake Lamprey; *Entosphenus macrostomus*) is listed as a threatened species under the *Species at Risk Act* (SARA). This species is endemic to three interconnected lakes on Vancouver Island, British Columbia. Cowichan Lake, one of the lakes in which this species resides, is a water reservoir managed to meet the downstream conservation and anthropogenic needs of the watershed. Currently Cowichan Lake water levels and outflows to the Cowichan River are controlled in part by the water control weir at the outlet of Cowichan Lake. Recent droughts in the Cowichan River watershed have resulted in lower than normal summer water levels in the lake which has resulted in reduced outflows to the river as well as dewatering of alluvial fans and lake margins. These dewatered areas include Vancouver Lamprey critical habitat, which is protected under SARA. Protection of Vancouver Lamprey's critical habitat from destruction was accomplished in February 2020 through a SARA critical habitat order made under subsections 58(4) and (5), which invoked the prohibition in subsection 58(1) against the destruction of the identified critical habitat. It is worth noting that protections under SARA apply to all aquatic species listed as extirpated, endangered or threatened regardless of whether the species is on federal or provincial lands. Decreased lake water levels potentially destroy critical habitat and negatively impact spawning and rearing for this species.

Fisheries and Oceans Canada's (DFO) Fish and Fish Habitat Protection Program (FFHPP) has requested that Science Branch provide science advice on the effect water management has on Vancouver Lamprey spawning and rearing habitat, as well as identification of other conservation issues and enhancement opportunities for critical habitat.

The assessment and advice arising from this Canadian Science Advisory Secretariat (CSAS) Science Response (SR) process will be used to inform resource managers on the water management of Cowichan Lake and support the development of current and new water use policy. It may also inform future water management decisions related to the design/operation of the new weir.

The specific objectives of this review are to:

1. Evaluate what range of water levels are required to provide maximum protection to Vancouver Lamprey and its critical habitat by life stage for adults (spawning), eggs (incubation), and ammocoetes (feeding and rearing), and when these water levels are required by the species for these life stages (i.e. biologically significant periods).
2. Evaluate how much critical habitat (in square meters or hectares) is being affected by lake draw downs, and at what lake elevations critical habitat starts being affected within the

normal range of current water management (full supply level and zero storage with minimum release of 7.08 m^3/s into the Cowichan River).

3. Identify conservation issues for Vancouver Lamprey and the types of potential enhancement or rehabilitation opportunities that may exist for this species in the Cowichan Lake watershed.
4. Examine and identify uncertainties in the data and methods.

This Science Response results from the regional peer review of January 18, 2023 on the effects of Cowichan Lake water management on Vancouver Lamprey in British Columbia and identification of possible enhancement opportunities.

Background

Vancouver Lamprey are freshwater parasitic fish found only in Cowichan, Bear and Mesachie lakes and the lower reaches of their tributaries on Vancouver Island, British Columbia (Figure 1). This species is listed as threatened under Schedule 1 of Canada's *Species at Risk Act* (SARA) due to being restricted in range and threatened by ongoing declines in habitat quality and quantity from water management and droughts which are increasing in frequency due to climate change (Committee on the Status of Endangered Wildlife in Canada [COSEWIC] 2017; Wade et al. 2021). SARA also provides for the identification and protection of critical habitat for listed endangered, threatened and extirpated species. For listed aquatic species, those protections are afforded regardless of whether the species occurs on provincial or federal lands. Under SARA critical habitat is defined as *"… the habitat that is necessary for the survival or recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species"*. SARA also defines habitat as "… *spawning grounds and nursery, rearing, food supply, migration and any other areas on which aquatic species depend directly or indirectly in order to carry out their life processes, or areas where aquatic species formerly occurred and have the potential to be reintroduced".* For Vancouver Lamprey critical habitat was identified as: Cowichan, Bear, and Mesachie lakes; Mesachie Creek (flowing between Bear and Mesachie lakes); the lower 100 m of eight tributaries flowing into Cowichan Lake; the lower 100 m of Halfway Creek flowing into Mesachie Lake; and, riparian widths of 15 to 30 m extending inland from aforementioned streams and two specific areas of Cowichan Lake (DFO 2019). Vancouver Lamprey nests also represent discrete dwelling places that support spawning and egg incubation, and are considered a "residence" for the species, and are also afforded protection under SARA. While for this species critical habitat and residence overlap, they are both independently protected under SARA.

Within this critical habitat, spawning adults and ammocoetes (larvae) of Vancouver Lamprey are thought to be dependent on alluvial fan habitat, shallow riparian habitats and mouths of inflowing rivers and streams for spawning and early rearing (Wade et al. 2018a; 2018b; Beamish and Wade 2008). Although knowledge gaps for the life history of this species exist, adults have been reported in spawning condition as early as May 3rd and as late as August 18th (Beamish and Wade 2008). It is not fully understood what the peak spawning period is within this window but it is believed to be relatively restricted and influenced by water temperatures. Ammocoetes, a blind, filter-feeding larval stage, may spend up to six years in this stage of development before metamorphosing into a parasitic adult. As Vancouver Lamprey are understudied, proxy information from other species with a similar life history are used where possible to inform some of the biological knowledge gaps that exist for this species (e.g., temperature requirements, number of years required for ammocoetes before metamorphosis, ammocoete mobility during dewatering events, and life span). However, even with some knowledge gaps there are aspects of the Vancouver Lamprey's life history, including timing and location of spawning and early rearing that make this species susceptible to the impacts of climate change, droughts and water management issues (Wade et al. 2021). Ensuring spawning and early rearing habitat is available and maintained by sufficient water levels throughout the year is therefore important for the survival of this species.

Cowichan Lake is a large, regulated water body which serves as a reservoir to meet downstream conservation and anthropogenic needs. Lake and river water levels are managed in season (from April 1st to October 31st) through operation of a weir constructed in 1957 at the outflow of Cowichan Lake to Cowichan River and guided by established protocols (Vessey et al. 2008). However, operational guidelines do not currently consider the temporal or spatial habitat requirements of Vancouver Lamprey, and lower lake water levels through water release from the weir, or emergency pumping below established storage levels into negative storage, can dewater habitat the species requires for spawning and rearing (i.e., critical habitat and residence).

Given the impact of water management on the Vancouver Lamprey, identifying additional conservation issues for Vancouver Lamprey and potential enhancement opportunities may also help mitigate current direct and indirect threats to the species.

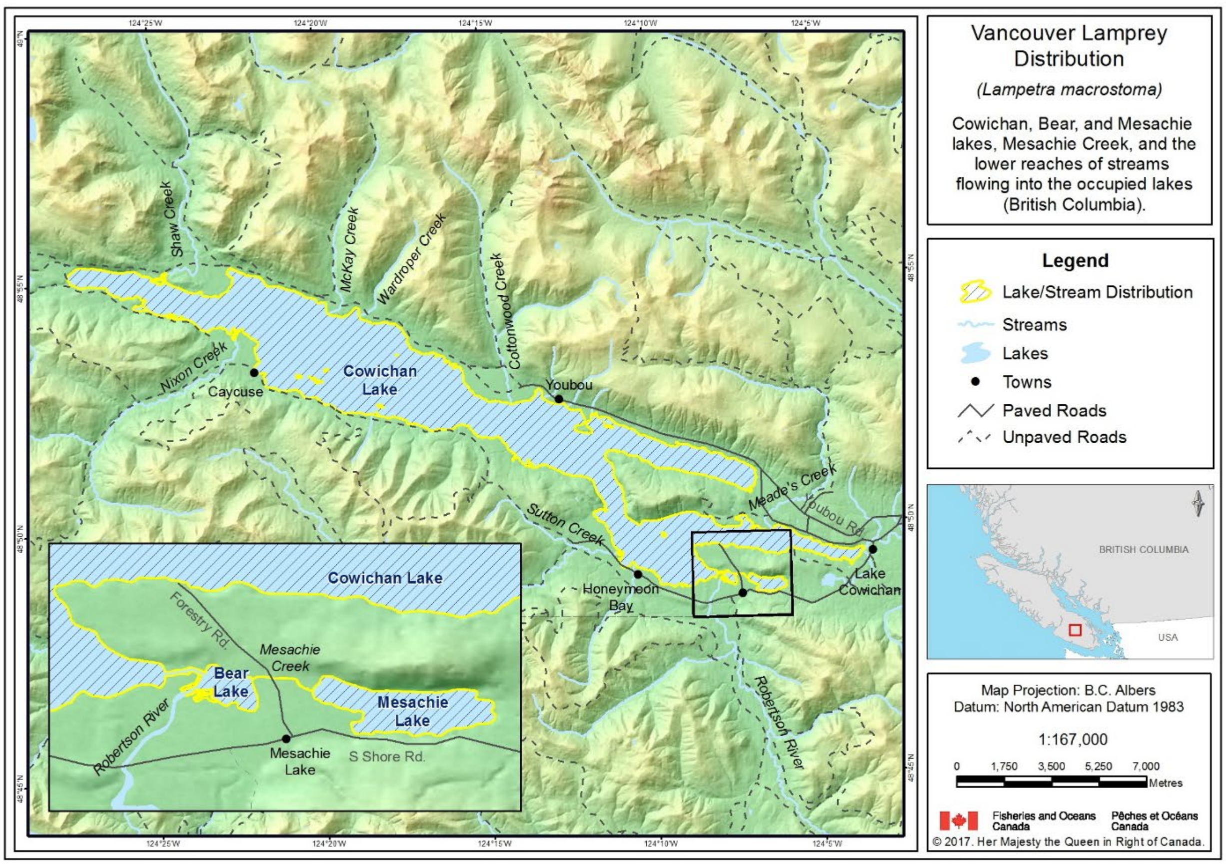

Figure 1. Distribution of Vancouver Lamprey (Source: Fisheries and Oceans Canada 2019 Action Plan).

Analysis and Response

Objective 1: Evaluate what range of water levels are required to provide maximum protection to Vancouver Lamprey and its critical habitat by life stage for adults (spawning), eggs (incubation), and ammocoetes (feeding and rearing), and when these water levels are required by the species for these life stages (i.e., biologically significant periods)

Water levels in Cowichan Lake have of number of different drivers including environmental drivers such as precipitation, snowpack melting, temperature, and evaporation loss. Anthropogenic drivers primarily consist of weir operation and water withdrawal to meet the downstream conservation and anthropogenic needs of the watershed, including industry withdrawals. While inter-annual variation is expected, some climate change models suggest increased frequency and severity of droughts, higher temperatures and reduced snowpack and precipitation in the winter storage period, resulting in potentially greater shortfalls in summer water supply (Cowichan Valley Regional District [CVRD] 2021).

Within Cowichan Lake, Vancouver Lamprey are dependent on alluvial fan habitat, shallow riparian habitats and mouths of inflowing rivers and streams for spawning and early rearing (Wade et al. 2021; 2018a; 2018b; Beamish and Wade 2008). Decreases in lake water levels result in alluvial fan habitat, part of the identified critical habitat for the species, and their residences or nests becoming dewatered (Wade et al. 2021; Chaudhuri et al. 2020). The relationship between lake water levels and available alluvial fan habitat for this species demonstrates the importance of the control and management of the weir for the survival of this species.

Two studies used aerial surveys to quantify the relationship between availability of spawning, egg incubation, and early rearing habitat within alluvial fans, and lake water levels (see Wade et al. 2021 and Chaudhuri et al. 2020 for more details). These studies used the ‘assumed datum’, for lake water levels, which is a local coordinate system for Water Survey of Canada Station 08HA009 that provides a gauge reading of water level in the lake based on a bench mark, and does not reflect the depth of water nor its height above sea level. The Canadian Geodetic Vertical Datum of 2013 (CGVD2013) is now the new reference standard for heights across Canada and will be used in the new weir design and form the basis of new water licenses associated with the weir. Therefore, results will be provided in both datums to align with previously published results and to be relevant to current management decisions. Conversion of the assumed datum for 08HA009 is possible by adding 160.94 m (equivalent to zero of the local assumed datum) to convert to geodetic datum CGVD 28. Subsequently, adding 0.2 m transforms CGVD 28 data to CGVD2013 (Water Survey of Canada 2013). Results are provided in the assumed datum followed by CGVD2013 in brackets.

The existing weir provides a total of 0.97 m of storage (from full storage to where minimum licensed outflow of 7.08 m^3/s can be maintained. This corresponds to 1.426 m to 0.456 m (162.57 m to 161.6 m CGVD2013). Elevations above full storage can typically occur during fall and winter. Below 0.456 m (161.6 m CGVD2013), flows decline as the lake level drops until 0.346 m (161.49 CGVD2013) at which point, minimal continued flows (typically 4.5 m^3/s) can only be maintained by pumping over the weir. Zero storage identified in this Science Response is based on the assumed datum of 0 m (161.14 m CGVD2013), which is 0.346 m below the zero storage (0.346 m; 161.49 m CGVD2013) based on weir operation.

When water levels approached zero storage (0 m assumed datum, 161.14 m CGVD2013), less than 10% of alluvial fan habitat required for spawning and early rearing was covered in water and potentially available within Cowichan Lake for Vancouver Lamprey (Figure 1; Wade et al. 2021). Water levels at 1 m (162.14 m CGVD2013) generally ensured more than 50% of alluvial fan habitat was available, and water levels of 1.5 m (162.64 m CGVD2013) and greater generally ensured the majority of alluvial fan habitat was available (Figure 1; Wade et al. 2021). While there is variability across sites due to different bathymetry and environmental features, these results provide general guidelines for all alluvial fan habitats within Cowichan Lake and are consistent with Chaudhuri et al. (2020), which looked at availability of alluvial fan habitat at one site (Robertson River) in Cowichan Lake. Therefore to provide maximum protection to Vancouver Lamprey, it is recommended lake water levels are above 1.5 m (162.64 m CGVD2013), and do not fall below 1 m (162.14 m CGVD2013).

As new information becomes available, and changes to the alluvial fans occur, the assumptions regarding spawning and early rearing habitat delineation and availability in relation to water management, may need to be updated.

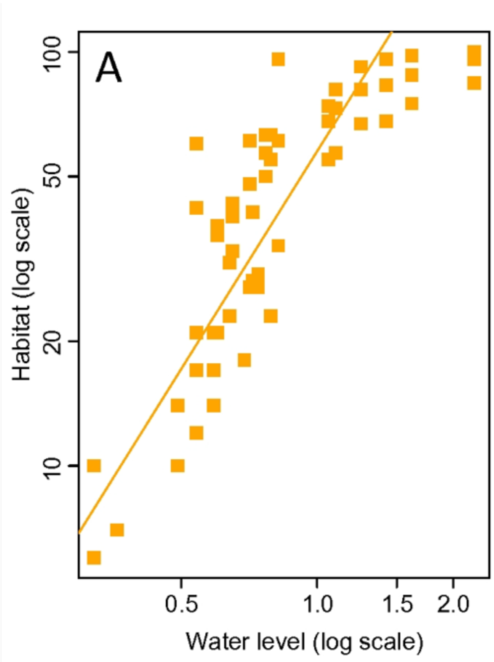

Figure 2. The relationship between water level (assumed datum) and percent of available alluvial fan habitat was calculated using Standardised Major Axis (SMA) model with log scale fit results. See Wade et al. (2021) for further details on model.

Aspects of Vancouver Lamprey's life history, including habitat use during different life stages, can also make Vancouver Lamprey more or less susceptible to the impacts of droughts, climate change and lake water levels (Wade et al. 2021). Therefore it is important to address what the habitat requirements and biologically significant periods are across life stages.

Adult spawning and egg incubation

Adult Vancouver Lamprey are dependent on alluvial fan habitat, shallow riparian habitats and mouths of inflowing rivers and streams within Cowichan, Bear and Mesachie lakes for spawning and egg incubation (Wade 2019; Wade et al. 2018a; 2018b; Beamish and Wade 2008). Lamprey are terminal spawners, but it is not known if Vancouver Lamprey home to their natal spawning grounds, or if habitat at natal spawning grounds is unavailable, whether the species is able to seek out other alluvial fan habitat. It is also unknown if all potential spawning habitat is equally utilized or if it is skewed and the species primarily uses a smaller subset of alluvial fan habitats. Although knowledge gaps for the species remain, current evidence suggests the spawning window for Vancouver Lamprey is as early as May 3rd, and as late as August 18th (Wade 2019; Wade et al. 2018a; 2018b; Beamish and Wade 2008). However, there is likely a narrower, peak spawning period within that window.

Adults also appear to be restricted to alluvial fan habitat at the mouths of tributaries for nest building and spawning (Wade 2019; Wade et al. 2018a; 2018b). Knowledge gaps remain regarding the depth or temperature of water required for spawning and egg incubation (i.e., what portion of available wetted habitat is biologically available). However, it is not believed that increased water depths resulting from greater weir storage or earlier storage would be a limiting factor, and would only benefit the species by ensuring alluvial fans were covered with water for a longer period of time. Limited data for Vancouver Lamprey show nest building, spawning and egg incubation have occurred in water depths of 42–65 cm (Wade at al. 2018b). For other species of freshwater parasitic lamprey which build nests in tributaries, water depths for successful nest building, spawning and egg incubation ranges from 18–30 cm (Cochran 2014) and possibly up to 90 cm (Mormon 1979) for Chestnut Lamprey (*Ichthyomyzon castaneus*). Silver Lamprey (*I. unicuspis*) have been reported building nests in 23–79 cm deep water (Mormon 1979). Silver Lamprey also spawn in deeper water when using nests already made by the Sea Lamprey (*Petromyzon marinus*) (Cochran and Lyons 2004). The lake spawning Miller Lake Lamprey (*Entosphenus minimus*) has been reported to build nests in water depths of 30 cm (Lorion et al. 2000).

Temperature thresholds and the role of water temperature and associated water depths on behaviour, growth rates, egg development and mortality remains unknown for Vancouver Lamprey. Duration of egg incubation under different temperature regimes are also unknown for Vancouver Lamprey. Chestnut Lamprey eggs hatch in 9–14 days at 18.4˚C (Smith et al. 1968); eggs from Korean Lamprey, which are similar in maximum size to adult Vancouver Lamprey, hatch in 10 days at 18˚C (Feng et al. 2018). However, there is potential for water temperatures to exceed thresholds required for successful spawning and egg incubation when insufficient water is available.

Therefore to provide maximum protection for spawning adults and egg incubation, it is recommended that lake water levels are above 1.5 m (162.64 m CGVD2013), and do not fall below 1 m (162.14 m CGVD2013) from early May to September, to provide time for eggs deposited at the end of the spawning window (August) to develop and hatch. Within alluvial fan habitats it is believed at least 40 cm of water may be required, although there are associated uncertainties with this.

Ammocoetes (feeding and rearing)

After hatching, ammocoetes, a blind, filter-feeding larval stage, burrow into a range of substrates varying from mud to loam, to firm sand and small-large pebbles within alluvial fan and nearshore habitats (Wade and MacConnachie 2016). There is limited data to inform dispersal distance or water depths Vancouver Lamprey ammocoetes prefer or are typically found at. They have been found at similar depth ranges as spawning adults and egg incubation (i.e., 42–65 cm), but on one occasion were found at depths of 2 m deep within alluvial fan habitat (Beamish and Wade 2008). It is unknown how deep ammocoetes could potentially be found in lake habitats, due to limitations of survey methods and potential harm to the species. Ammocoetes of the Chestnut Lamprey are typically found in water between 15–61 cm deep (Holt and Durkee 1983); Miller Lake Lamprey have been collected along the margins of lakes in water less than 1 m (Kan and Bond 1981).

Ammocoetes are not uniformly distributed across nearshore habitat but can be locally abundant (Beamish 1982; Wade and MacConnachie 2016) within restricted areas. The reasons for this distribution and whether it is related to dispersal, substrate, microhabitat conditions or other factors remains unknown. Within sites, Vancouver Lamprey ammocoete lengths are also highly variable from 4.2–13.2 cm indicating many year classes are present (Wade and MacConnachie 2016).

Lampreys spend the majority of their life cycle as ammocoetes. While the duration of this life stage is not known for Vancouver Lamprey, Beamish (2001) estimated it as 6 years for this species. Duration of the ammocoete stages for other parasitic freshwater lampreys varies from 2.5 years for Miller Lake Lamprey (Kan and Bond 1981) and up to 7 years for both Chestnut (Lanteigne 1981) and Silver lampreys (Scott and Crossman 1973).

There are further knowledge gaps when it comes to ammocoete mobility, their ability to relocate to other more suitable habitat in the event of dewatering, and the survival rate of various ammocoete age classes at specific sites and substrate types. The effects of water removal or drawdowns on ammocoetes has been studied in the United States largely within the context of dewatering regulated rivers. The main species of focus has been the Pacific Lamprey (*E. tridentatus*), although studies such as Liedtke et al. (2015) used a combination of both Pacific Lamprey and Western Brook Lamprey (*Lampetra richardsoni*) ammocoetes. Both laboratory studies (Liedtke et al. 2015; Liedtke et al. 2020) and field studies (Harris et al. 2020) have been conducted in recent years to understand the population level effects of dewatering on ammocoetes. As there is no comparable study to inform the effects of dewatering on Vancouver Lamprey ammocoetes, these studies can help inform decision making.

A field study (Harris et al. 2020) and a laboratory study (Liedtke et al. 2015) both showed that approximately 50% of ammocoetes emerged during drawdowns, the remainder either emerged after dewatering or remained in the sediment. Emergence can occur when habitat becomes less suitable. A subsequent laboratory study by Liedtke et al. (2020) reported between 50–80% of ammocoetes did not initiate movement in response to dewatering. Of those that did, approximately 30% emerged during the dewatering trials; these were consistently the small ammocoetes while the larger ones tended to stay burrowed (Liedtke et al. 2020). Variables such as difference in species, substrate composition and type were suggested as potential reasons for differences between studies (Liedtke et al. 2015; 2020). Faster dewatering rates also generally resulted in higher percentages of stranded ammocoetes (Liedtke et al. 2020; 2015).

While ammocoetes can survive short exposures to dewatering, mortality increases as exposure exceeds 24 hrs (Liedtke et al. 2015). By 48 hrs, mortality is consistently greater than 60% (and up to 90%) (Liedtke et al. 2015), with lamprey that remained burrowed having improved survival than those that emerged.

While the impact of dewatering of alluvial fan or nearshore habitat on Vancouver Lamprey ammocoetes is unknown, the results of these studies for other lamprey suggest limited ammocoete mobility during dewatering events. Due to the length of time ammocoetes are buried in sediment, a dewatering event would have negative impacts on multiple year classes simultaneously.

Table 1. Recommendations for minimum water depth for sensitive life history stages.

Life Stage	Habitat	Minimum lake level required to provide maximum protection	Minimum water depth (cm) at localized sites	Biologically Significant Period
Spawning	Alluvial fan	above 1.5 m (162.64 m CGVD2013), and not below 1 m (162.14 m CGVD2013).	~40 cm	May to September*
Egg incubation	Alluvial fan	above 1.5 m (162.64 m CGVD2013), and not below 1 m (162.14 m CGVD2013).	~40 cm	May to September*
Ammocoete	Alluvial fan	above 1.5 m (162.64 m CGVD2013), and not below 1 m (162.14 m CGVD2013).	~40 cm	Year round
Ammocoete	Nearshore	above 1.5 m (162.64 m CGVD2013), and not below 1 m (162.14 m CGVD2013).	~40 cm	Year round

* May to September is identified here to provide time for eggs deposited at the end of the spawning window (August) to develop and hatch.

While these recommendations are based on the biological needs of the species, specific to lake levels required to maintain spawning habitat, there are challenges in meeting these goals with the current storage capacity during the spawning period and throughout the year.

Objective 2: Evaluate how much critical habitat (in square meters or hectares) is being affected by lake draw downs, and at what lake elevations critical habitat starts being affected within the normal range of current water management (full supply level and zero storage with minimum release of 7.08 m^3/s into the Cowichan River)

Vancouver Lamprey critical habitat includes the entirety of Cowichan, Bear, and Mesachie lakes, tributary deltas and surrounding nearshore lake habitat, stream habitat, pelagic lake habitat, and riparian habitat of 15 to 30 m in width from the high water mark in streams (see DFO 2019). The entire extent of this critical habitat is protected under SARA. The estimated surface area of these lakes is 6,277 ha (Cowichan Lake = ~6,204 ha; Bear Lake = ~15 ha; Mesachie Lake = ~58 ha).

Within this critical habitat, adult Vancouver Lamprey are thought to be dependent on alluvial fan habitat for spawning and egg incubation, while ammocoetes are thought to be dependent on alluvial fan and nearshore habitat for early rearing and development (Beamish and Wade 2008; Wade et al. 2018a; 2018b). Lamprey are terminal spawners, and while it is not known if Vancouver Lamprey home to their natal spawning grounds, the role of freshwater flowing from tributaries is likely important for successful spawning and egg incubation. Within a range of normal variation, adequate substrate, water flow, minimum water depth, water quality parameters (oxygen, temperature, pH) are all required for successful spawning, egg incubation, and early rearing (DFO 2019).

Vancouver Lamprey may not utilize all potential spawning habitat equally and may select a smaller subset of alluvial fan habitats preferentially. The alluvial fan habitats where adults are known or likely to utilize for spawning and egg incubation consist of Cottonwood Creek (~0.2 ha), Robertson River (~1 ha), Shaw Creek (~0.8 ha), and Nixon Creek (~0.6 ha). While available spawning, egg incubation and early rearing habitat within these alluvial fans is subject to annual variation, the total is approximately 2.6 ha (Wade et al. 2021). This small area represents a small proportion of total critical habitat (0.04%), but is essential for the survival of Vancouver Lamprey. Essentially 100% of the population is likely dependent on these small areas, and impact to these areas can result in population level impacts for the species.

When water levels approached zero storage (i.e., 0 m water assumed datum, 161.14 m CGVD2013), less than 10% of alluvial fan habitat is potentially available across Cowichan Lake for Vancouver Lamprey (Wade et al. 2021), which only equates to approximately 0.26 ha. Water levels at 1 m (162.14 m CGVD2013) generally ensured more than 50% of alluvial fan habitat or 1.3 ha was available, and water levels of 1.5 m (162.64 m CGVD2013) and greater generally ensured the majority of alluvial fan habitat or close to 2.6 ha was available (Wade et al. 2021).

It is also important to note that these calculations only estimate potential available habitat within alluvial fans, and do not consider what is biologically available for Vancouver Lamprey in terms of sufficient water depth, temperature or other environmental or water quality variables. There is also annual variation regarding the degree of alluvial fan habitat that is available, based on different drivers such as precipitation, snowpack melting, temperature, evaporation loss, water quality, and anthropogenic drivers such weir operation and water withdrawal to meet downstream conservation and anthropogenic needs of the watershed. Another major driver is sedimentation and accumulation of sediment load within alluvial fan habitat. Alluvial fans are highly influenced by downstream transport of sediments (from sand to large rocks) and large woody debris. The accumulation of sediment or aggradation plays a large role in the amount of available water required (depth and area) to support spawning, egg incubation and early rearing and sediment loadings may be highly variable from year-to-year.

Nearshore habitat is also required by ammocoetes for early rearing. However, no data is available to calculate the area (ha) of nearshore habitat within the identified critical habitat for Vancouver Lamprey, the degree and spatial extent this habitat type is being utilized, nor the degree it could be affected by various lake water levels. Nearshore habitat will vary due to differences in bathometry and this habitat type will not be equally utilized across all the critical habitat available. However, it has been demonstrated in other lamprey species that ammocoetes have limited mobility and survival during dewatering events (Liedtke et al. 2015, 2020; Harris et al. 2020). Therefore, ensuring alluvial fan habitat is wetted would also provide some level of protection against dewatering to both alluvial fan and nearshore habitat, and help maintain early rearing habitat for ammocoetes.

Objective 3: Identify conservation issues for Vancouver Lamprey and the types of potential enhancement or rehabilitation opportunities that may exist for this species in the Cowichan Lake watershed

Due to the many biotic and abiotic uncertainties specific to the conservation of this species, ensuring resilience, minimizing harms and engaging in enhancement opportunities are actions that can directly influence and enhance population health (Stephen and Wade 2018; Stephen et al. 2018). A table summarizing conservation issues and rehabilitation actions directly related to lake levels in Mesachie, Bear and Cowichan lakes is provided below (Table 2).

One of the potential enhancement opportunities suggested below is the removal of excess sediment from alluvial fans (outside of the spawning window) to create more available spawning habitat. This enhancement opportunity requires more detailed studies to understand the feasibility and potential benefits on a site by site basis. While sediment extraction from streams can potentially degrade fish habitat, alluvial fans can continue to accumulate sediment that exceeds the ability of the river to transport material across the fan and beyond, resulting in the alluvial fan aggrading as additional sand and gravel are deposited year after year. This effect can be exacerbated in situations where sedimentation rates have increased due to anthropogenic activities. Adequate stream flows may not prevent aggradation and maintenance of spawning habitat, but result in channelization of tributaries and alluvial fans, and here it is the alluvial fans that often represent unique habitats within riverine systems.

The aggradation of alluvial fans, stream flow and lake water levels are some of the site specific variables that can contribute to or limit the Vancouver Lamprey accessing and utilizing this habitat type during critical life stages (Figure 2). In Cowichan Lake, aggradation and low lake levels have resulted in alluvial fan habitat becoming dewatered prior to peak spawning periods within the spawning window. Removal of excess sediment could contribute to maintaining spawning habitat for Vancouver Lamprey, even with lower lake water levels. Therefore, for alluvial fans which have excess sediment that are at risk of being dewatered with low lake water levels during the spawning period, removal of excess sediment could be evaluated to determine the conservation benefits for Vancouver Lamprey. Creation of sediment traps could also be highly beneficial and provide some level of protection and stability to spawning habitat from continual aggradation.

Figure 3. Downstream transport of sediment, impacting alluvial fan at Robertson River in 2022.

Table 2. Conservation issues and options for rehabilitation actions proposed for Vancouver Lamprey specific to water management and weir operations.

Conservation Issue	Rehabilitation action
Knowledge gaps that inhibit conservation of Vancouver Lamprey	• Information on the range of water quality variables (e.g., flow, depth, temperature, dissolved oxygen, pH) required for successful spawning, egg incubation and early rearing. This would help inform the amount of habitat that is biologically available for life stages. • Understanding annual and seasonal variability of water levels and access to spawning habitat on Vancouver Lamprey. A new weir will likely help alleviate much of this issue, but the qualities of these critical habitats should be monitored in a continually changing environment to ensure spawning habitat is provided. • Vancouver Lamprey ammocoete mobility and survival across different year classes during dewatering events.

Conservation Issue	Rehabilitation action
	• Modeling nearshore habitat availability and ammocoete use across various lake water levels would contribute to understanding potential impacts of water management. • Site specific studies to understand the feasibility and potential benefits of excess sediment removal and surveys to determine if there are alluvial fans that could potentially benefit from additional substrate, where habitat is potentially lacking. • Influence of steam flow in mitigating aggradation of alluvial fan habitat and impacts of channelization within spawning habitat.
Access to spawning habitat (alluvial fan) throughout the species' range	• Removal of excess sediment from alluvial fans outside of the spawning period or when dry. This action requires more detailed studies to understand the feasibility and potential benefits on a site by site basis. It may have potential to restore habitat significantly impacted by high levels of aggradation. However, it may be a temporary fix requiring annual work due to the major sediment load carried by Cowichan Lake tributaries. • Installing sediment traps could provide some level of protection to spawning habitat, and may provide stability of spawning habitat. However, further site specific studies are required to identify suitable locations and feasibility, and ongoing maintenance would be required for effective functioning until upslope areas stabilize over time. • Understand and manage the upstream effects of logging or residential development on tributaries to Cowichan, Bear and Mesachie lakes and alluvial depositions. Identify areas for potential remediation to reduce rock and gravel output, increase flow during the dry season. • Maintaining adequate lake water levels from May to September. To provide maximum protection to Vancouver Lamprey, it is recommended lake water levels are above 1.5 m (162.64 m CGVD2013), and do not fall below 1 m (162.14 m CGVD2013). • Construction of a new weir (planning underway) to increase storage and provide more flexibility for managers to maintain ecological needs of the lakes and downstream habitats. This measure would be extremely helpful for the conservation of Vancouver Lamprey.
Ensure connectivity between Mesachie Lake and Bear/Cowichan lakes	• Mesachie Creek is the only means of connectivity for Vancouver Lamprey and prey to access Mesachie and Cowichan lakes. Previously, Mesachie Creek was a functional connection between these water bodies and allowed for prey and lamprey movement. This connection has been degraded over time and is no longer functional, isolating Mesachie Lake from Cowichan Lake.

Conservation Issue	Rehabilitation action
	Surveys to identify issues along the course of this creek have been conducted, but development and implementation of a restoration plan is required to restore this identified critical habitat for Vancouver Lamprey and mitigate impacts to the species.
Degradation of nearshore habitat	• Planting of native vegetation in riparian habitats along the lakeshore and lower reaches of tributaries. Further studies to identify priority areas for riparian restoration to benefit Vancouver Lamprey would be beneficial and enable this work to be completed.
Outreach	• Communicate the current regulations and importance of riparian habitat to stream and lakeshore residents. Some outreach has been conducted successfully and there are strong and engaged stewardship groups interested in Vancouver Lamprey. However, this is activity is more effective if communication is on-going.
Enforcement	• Enforce critical habitat protection for Vancouver Lamprey, as outlined in the *Species at Risk Act* (SARA) and BC's Riparian Area Regulations under the *Riparian Areas Protection Act*.

Objective 4: Examine and identify uncertainties in the data and methods

There are many uncertainties specific to the recommendations of this advice, mostly associated with knowledge gaps.

- Due to limited information, proxy species (lamprey with similar life histories) are used to inform some aspects of biology for Vancouver Lamprey.
- There are a number of knowledge gaps which limit our understanding of the biology, and the potential associated impacts to the species (i.e., water depth, temperature and other water quality variables required for spawning, egg incubation and early rearing; ammocoete mobility; ability and consequences of potential homing to natal grounds; role of tributaries in successful spawning and egg incubation; spatial extent and utilization of nearshore habitat). Calculations therefore only estimate potential available spawning habitat within alluvial fans (which are continually changing), and do not consider what is potentially biologically available for Vancouver Lamprey. This is important, as wetted habitat may not represent what is biologically available to the species due to thermal preferences and tolerances in spawning and rearing habitat.
- Annual variation in watershed drivers coupled with different sedimentation loading rates within tributaries and alluvial fan habitats results in uncertainties as to whether recommendations would remain valid. Continual monitoring is likely needed to provide current information as conditions change.
- Removal of excess sediment from alluvial fans (outside of the spawning window) to create more available spawning habitat, requires more detailed studies to understand the feasibility and potential benefits on a site by site basis. Conversely, although it is not expected that other alluvial fan habitat in Cowichan Lake would benefit from additional substrate to create more habitat, this would also require more detailed studies.

- There are currently no data available to calculate the area (ha) of nearshore habitat (rearing habitat for ammocoetes) within the identified critical habitat for Vancouver Lamprey, the degree and spatial extent this habitat type is being utilized, or the degree it could be affected by various lake water levels. Bathymetry data could be used to identify the littoral zone, which could be used as a proxy for nearshore habitat, but that data is not currently available.

Conclusions

There is sufficient information regarding the biology and habitat utilization for Vancouver Lamprey to provide recommendations on lake water levels required to provide maximum protection by life stage, area of critical habitat being impacted, potential conservation issues, enhancement opportunities and sources of uncertainty.

To provide maximum protection to Vancouver Lamprey, it is recommended lake water levels are above 1.5 m (162.64 m CGVD2013), and do not fall below 1 m (162.14 m CGVD2013). When water levels approached zero storage (0 m assumed datum, 161.14 m CGVD2013), less than 10% (0.26 ha) of alluvial fan habitat required for spawning and early rearing was covered in water and potentially available within Cowichan Lake for Vancouver Lamprey (Figure 1; Wade et al. 2021). Water levels at 1 m (162.14 m CGVD2013) generally ensured more than 50% (1.3 ha), of alluvial fan habitat was available, and water levels of 1.5 m (162.64 m CGVD2013) and greater generally ensured the majority (close to 2.6 ha) of alluvial fan habitat was available (Figure 1; Wade et al. 2021). While there is variability across sites due to different bathymetry, aggradation of alluvial fan habitat, stream flow and other environmental features, these results provide general guidelines for all alluvial fan habitats within Cowichan Lake.

While these recommendations are based on the biological needs of the species, specific to lake levels required to maintain spawning habitat, there are challenges in meeting these goals with the current storage capacity during the spawning period, which highlights the importance of increasing storage capacity to contribute to the conservation of this species. A new weir will help alleviate this issue, but it is recognized that maintaining high water levels throughout the year is currently unachievable, and that critical habitat should be monitored, in a continually changing environment.

The existing weir only provides a total of 0.97 m of storage (from full storage to where minimum licensed outflow of 7.08 m^3/s can be maintained, corresponding to 1.426 m to 0.456 m (162.57 m to 161.6 m CGVD2013). Elevations above full storage typically only occur during fall and winter. Below 0.456 m (161.6 m CGVD2013), flows decline as the lake level drops until 0.346 m (161.49 CGVD2013) at which point minimal continued flows are only be maintained by pumping over the weir, further lowering lake water levels. During the spawning period, lake levels frequently drop below 0.346 m (161.49 CGVD2013), so there are significant challenges in meeting recommended lake levels to ensure sufficient wetting of critical habitat, and spawning habitat is available. Over time, aggregation of some alluvial fans has also likely contributed to the need to have higher lake water levels. The proposed design of the new weir will increase the full storage elevation by 0.7 m. Furthermore, the proposed operational protocol would allow storage of water a month earlier (date shifting from April 1st to March 1st). Both of these measures would help enable more effective protection of critical habitat and maintain spawning habitat within alluvial fans. There is no question that raising the weir height and storage, coupled with new operational protocols, would have direct conservation benefits for Vancouver Lamprey. Higher lake levels are not anticipated to have negative impacts on the species or impact the creation or sustainability of alluvial fan habitat.

As new information becomes available, and changes to the alluvial fans occur, the assumptions regarding spawning and early rearing habitat delineation and availability in relation to water management will need to be updated. These recommendations relate to available habitat within alluvial fans across Cowichan and Bear lakes, but do not consider what is biologically available for Vancouver Lamprey in terms of sufficient water depth, temperature or other environmental or water quality variables.

Aspects of Vancouver Lamprey's life history, including habitat use during different life stages, can also make Vancouver Lamprey more or less susceptible to the impacts of droughts, climate change and lake water levels (Wade et al. 2021). Therefore it is important to address what the habitat requirements and biologically significant periods are across all life stages. For spawning and egg incubation, the biologically significant periods to maintain recommended lake water levels are from early May until September. There is limited data to inform what water depths or temperature Vancouver Lamprey adults require for successful spawning or egg incubation, but it is suggested a minimum of 40 cm of water be present during spawning and egg incubation within alluvial fan habitat. How this is achieved will depend on a variety of site specific factors including stream flow, aggradation, substrate and lake water levels.

For early rearing, Vancouver Lamprey ammocoetes are estimated to spend 6 years buried in alluvial fan and nearshore substrate as filter feeders. There are also uncertainties regarding ammocoete mobility and survival during dewatering events, which provide challenges in assessing population level impacts. However, recommendations to protect alluvial fan habitat would also likely provide similar protection of nearshore habitat and help maintain early rearing habitat for ammocoetes.

There are also challenges when trying to evaluate the area of critical habitat being affected by lake water levels. Vancouver Lamprey may not utilize all potential spawning habitat equally and may select a smaller subset of alluvial fan habitats preferentially. There are also no data to calculate the area (ha) of nearshore habitat, the degree and spatial extent this habitat type is being utilized and the degree it could be affected by various lake water levels. The area of alluvial fan habitat adults use for spawning and egg incubation is subject to annual variation, but totals approximately 2.6 ha. This small area represents a small proportion of total critical habitat available (0.04%), but is essential for the survival of Vancouver Lamprey, and impacts to these areas can have population impacts on the species.

There may be opportunities to ameliorate or restore Vancouver Lamprey critical habitat to help build population level resilience in a changing environment. The three most significant actions are likely 1) removal of excessive sediment on alluvial fans and riparian remediation 2) stream and riparian rehabilitation of Mesachie Creek and, 3) determining and minimizing the negative, upstream effects of tributaries on alluvial fans and riverine flow.

Removal of excess sediment from alluvial fans (outside of the spawning window) to create more available spawning habitat, requires more detailed studies to understand the feasibility and potential benefits on a site by site basis. At present, one potential site where gravel removal could be beneficial is the alluvial fan at Robertson River. High levels of aggradation at this site is impacting available spawning habitat, which requires higher lake water levels to provide suitable habitat at this site. There is also a need to remediate Mesachie Creek to maintain connectivity with the rest of the system, as it is currently not a functional connection and is isolating Mesachie Lake from Cowichan Lake. Historically, Mesachie Creek was a functional connection, but has been degraded over time, and no longer allows for movement of lamprey or prey between these water bodies.

There is no doubt that a changing climate and increased water demands have necessitated increased water storage capabilities in Cowichan Lake (Wade et al. 2021). The construction of a new weir which can store more water during sensitive times of the year will benefit both downstream (Cowichan River) as well as upstream (Cowichan Lake system) conservation goals. Lake conservation goals are not included in the current weir management plan, despite all aquatic species listed as an extirpated, endangered or threatened and being afforded legal protection under the *Species at Risk Act* (SARA) regardless of whether the species is on federal or provincial lands. As both critical habitat and residence for Vancouver Lamprey are being impacted by environmental and anthropogenic drivers in the watershed, the needs of the species should be incorporated into weir operation protocols to ensure the habitat the species requires for survival is protected and direct harm to the population is mitigated. As higher lake water levels would enhance the ability to protect critical habitat and have direct conservation benefits for Vancouver Lamprey.

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Sources of Information

Beamish, R.J. 1982. *Lampetra macrostoma*, a new species of freshwater parasitic lamprey from the west coast of Canada. Can. J. Fish. Aquat. Sci. 39:736–747.

Beamish, R.J. 2001. Updated status of the Vancouver Island Lake Lamprey, *Lampetra macrostoma*, in Canada. Can. Field-Nat 115:127–130.

Beamish, R.J. and Wade, J. 2008. Critical habitat and the conservation ecology of the freshwater parasitic lamprey, *Lampetra macrostoma*. Can. Field-Nat. 122(4):327–337.

Chaudhuri, C., Wade, J., and Robertson, C. 2020. Fluctuating water levels influence access to critical habitats for threatened Cowichan Lamprey. Facets 5:488–502.

Cochran, P.A. 2014. Field and laboratory observations on the ecology and behaviour of the Chestnut Lamprey *Ichthyomyzon castaneus*. J. Freshwater Ecol. 29(4):491–505.

Cochran, P.A. and Lyons, J. 2004. Field and laboratory observations on the ecology and behaviour of the Silver Lamprey (*Ichthyomyzon unicuspis*) in Wisconsin. J. Freshwater Ecol. 19 (2):245–253.

COSEWIC. 2017. COSEWIC assessment and status report on the Vancouver Lamprey *Entosphenus macrostomus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xi + 67 pp.

Cowichan Valley Regional District (CVRD). 2021. Climate Change Adaptation and Risk Management Strategy. 105 pp.

DFO. 2019. Action Plan for the Vancouver Lamprey (*Entosphenus macrostomus*) in Canada, 2019. Species at Risk Act Action Plan Series. Fisheries and Oceans Canada, Ottawa. iv + 39 pp.

Feng, B., Zhang, T., Wu, F., Chen, S. and Xu, A. 2018. Artificial propagation and embryonic development of Yalu River lamprey, *Lampetra morii*. Acta. Biochim. Biophys. Sin. 50(8):828–830.

Harris, J.E., Skalicky, J.J., Liedtke, T.L., Weiland, L.K., Clemens, B.J. and Gray, A.E. 2020. Effects of dewatering on behaviour, distribution, and abundance of larval lampreys. River Res. Applic. 1–12.

Holt, C.S. and Durkee, P.A. 1983. The distribution, ecology and growth of the Chestnut Lamprey, *Ichthyomyzon castaneus*, in the Clearwater River, Minnesota. J. Minn. Acad. Sci. 49:35–38.

Kan, T.T. and Bond, C.E. 1981. Notes on the biology of the Miller Lake Lamprey *Lampetra* (*Entosphenus*) *minima*. Northwest Sci. 55(1):70–74.

Lanteigne, J. 1981. The taxonomy and distribution of the North American lamprey genus *Ichthyomyzon*. M.Sc. thesis. University of Ottawa, Ottawa, Ontario. 150p.

Liedtke, T.L., Weiland, L.K. and Mesa, M.G. 2015. Vulnerability of larval lamprey to Columbia River hydropower system operations-Effects of dewatering on larval lamprey movements and survival. U.S. Geological Survey Open-File Report 2015–1157, 28p.

Liedtke, T.L., Weiland, L.K., Skalicky, J.J., and Gray, A.E. 2020. Evaluating dewatering approaches to protect larval Pacific lamprey: U.S. Geological Survey Open-File Report 2020–1026, 32p.

Lorion, C.M., Markle, D.F., Reid, S.B. and Docker, M.F. 2000. Redescription of the presumed-extinct Miller Lake Lamprey, *Lampetra minima*. Copeia 2000(4):1019–1028.

Morman, R.H. 1979. Distribution and ecology of lampreys in the Lower Peninsula of Michigan, 1957–75. Great Lakes Fish. Comm. Tech. Rep. No. 33. 59p.

Scott, W.B. and Crossman, E.J. 1973. Freshwater Fishes of Canada. Bulletin 184. Fisheries and Research Board of Canada, Ottawa.

Smith, A.J., Howell, J.H. and Piavis, G.W. 1968. Embryology of five species of lampreys of the upper Great Lakes. Copeia 1968:461–469.

Stephen, C. and Wade, J. 2018. Wildlife population welfare as coherence between adapted capacities and environmental realities: A case study of threatened lamprey on Vancouver Island. Front. Vet. Sci. 5:227.

Stephen, C., Wittrock, J. and Wade, J. 2018. Using a harm reduction approach in an environmental case study of fish and wildlife health. EcoHealth 15:4–7.

Vessey, M., Tutty, B., Wightman, C., Elliott, J.R., Rutherford, T., and Baillie, S. 2008. Cowichan weir start-up, operation and seasonal protocols.

Wade, J. 2019. Can we learn from other freshwater parasitic lampreys to help manage Cowichan Lake Lamprey (*Entosphenus macrostomus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 3184: v + 29 p.

Wade, J. and MacConnachie, S. 2016. Cowichan Lake Lamprey (*Entosphenus macrostomus)* ammocoete habitat survey 2012. Can. Manuscr. Rep. Fish. Aquat. Sci. 3088: iv + 15p.

Wade, J., Dealy, L., Hodes, V. and Grant, P. 2018a. Identifying factors contributing to the successful spawning and early rearing of Cowichan Lake Lamprey (*Entosphenus macrostomus*). Can. Manuscr. Rep. Fish. Aquat. Sci. 3169: v + 13 p.

Wade, J., Dealy, L. and MacConnachie, S. 2018b. First record of nest building, spawning and sexual dimorphism in the threatened Cowichan Lake lamprey *Entosphenus macrostomus*. Endanger. Species Res. 35:39–45.

Wade, J., Dealy, L., Stephen, C., Lewis, T. and Grant, P. 2021. Supporting climate change adaptation actions for the conservation of the threatened Cowichan Lake Lamprey through low cost monitoring of critical habitat. Can. Manuscr. Rep. Fish. Aquat. Sci. 3227: vi + 17 p.

Water Survey of Canada. 2013. Vertical datum information for 08HA009.

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