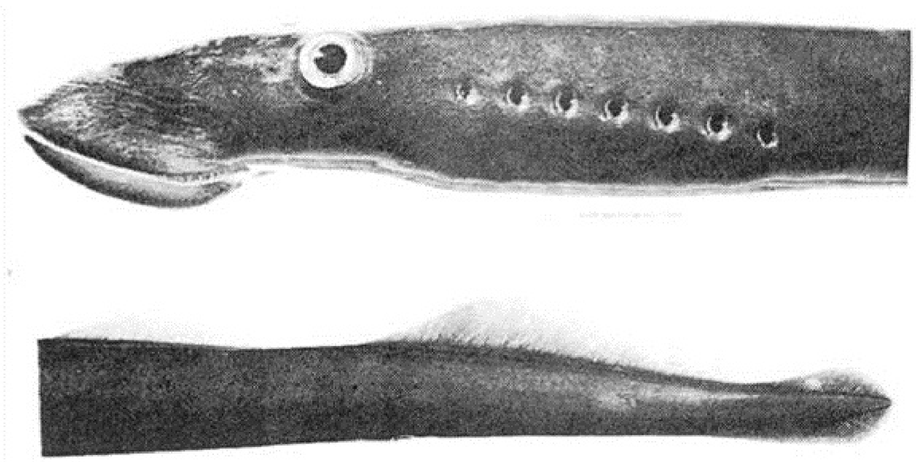
COSEWIC
Assessment and Status Report

on the

Vancouver Lamprey
Entosphenus macrostomus

in Canada



THREATENED
2017

COSEWIC
Committee on the Status
of Endangered Wildlife
in Canada

COSEPAC
Comité sur la situation
des espèces en péril
au Canada

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

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. (http://www.registrelep-sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1).

Previous report(s):

COSEWIC. 2008. COSEWIC assessment and update status report on the Vancouver Lamprey *Lampetra macrostoma* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 39 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

COSEWIC. 2000. COSEWIC assessment and update status report on the Cowichan Lake Lamprey *Lampetra macrostoma* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 9 pp.

Beamish, R.J. 1998. Update COSEWIC status report on the Cowichan Lake Lamprey *Lampetra macrostoma* in Canada, *in* COSEWIC assessment and update status report on the Cowichan Lake Lamprey *Lampetra macrostoma* in Canada. Ottawa. 1-9 pp.

Beamish, R.J. 1986. COSEWIC status report on the Lake Lamprey *Lampetra macrostoma* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 14 pp.

Production note:
COSEWIC would like to acknowledge Erin Spice and Dr. Margaret Docker for writing the status report on the Vancouver Lamprey *Entosphenus macrostomus* in Canada, prepared under contract with Environment and Climate Change Canada. This report was overseen and edited by Dr. John Post, Co-chair of the COSEWIC Freshwater Fishes Specialist Subcommittee.

For additional copies contact:

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

Tel.: 819-938-4125
Fax: 819-938-3984
E-mail: ec.cosepac-cosewic.ec@canada.ca
http://www.cosewic.gc.ca

Également disponible en français sous le titre Évaluation et Rapport de situation du COSEPAC sur la Lamproie de Vancouver (*Entosphenus macrostomus*) au Canada.

Cover illustration/photo:
Vancouver Lamprey — Provided by authors.

Catalogue No. CW69-14/562-2018E-PDF
ISBN 978-0-660-26678-7

COSEWIC
Assessment Summary

Assessment Summary – November 2017

Common name
Vancouver Lamprey

Scientific name
Entosphenus macrostomus

Status
Threatened

Reason for designation
This endemic parasitic fish is known from only three connected lakes and the lower reaches of larger tributaries within a single watershed on Vancouver Island. The species' spawning areas and juvenile rearing habitats have a restricted distribution in tributary deltas and lakeshore littoral habitat. Slow but ongoing declines in habitat quality and quantity due to threats from droughts and water management, sediment mobilized following upslope logging, and shoreline development threaten the species' long-term persistence.

Occurrence
British Columbia

Status history
Designated Special Concern in April 1986. Status re-examined and confirmed in April 1998. Status re-examined and designated Threatened in November 2000, in November 2008, and in November 2017.

COSEWIC
Executive Summary

Vancouver Lamprey
Entosphenus macrostomus

Wildlife Species Description and Significance

Vancouver Lamprey is a parasitic eel-shaped fish, with a round, sucker-like mouth which it uses to attach to the side of prey fishes. Adults range in size from 18 to 27 cm. The larger mouth and eye, and its ability to remain in fresh water throughout its parasitic feeding phase, distinguish Vancouver Lamprey from the closely related Pacific Lamprey.

Vancouver Lamprey is endemic to Canada and is known to occur in only three interconnected lakes on Vancouver Island. Although there is no commercial value to this species and it preys upon commercially valuable salmonid species, it contributes to biodiversity and plays an important role in the ecosystem. It is especially important for its scientific value. Lampreys are ancient fish providing insights into the origin and evolution of vertebrates, and Vancouver Lamprey represents an example of a relatively recent evolutionary divergence.

Distribution

Vancouver Lamprey is endemic to Canada, and is known to occur only in Cowichan, Bear, and Mesachie lakes on southern Vancouver Island, British Columbia, and the lower part of tributaries flowing into these lakes.

Habitat

Most spawning occurs on shallow gravel bars in nearshore lake habitat, and some spawning may occur in tributaries. After hatching, the larval lamprey (ammocoetes) burrow into soft fine sediments or sand. The juvenile lamprey likely seeks prey in the open lake.

Biology

The life cycle of Vancouver Lamprey consists of two distinct stages: a blind, filter-feeding larval stage (which lasts approximately 5-6 years) and a parasitic phase (which probably lasts less than 2 years). Metamorphosis into the juvenile stage (i.e., post-metamorphosis but prior to full sexual maturity) occurs from July to October. After overwintering in the gravel, the juvenile likely begins feeding on salmonids (especially Coastal Cutthroat Trout) in the open waters of Cowichan, Bear, and Mesachie lakes. It is believed that feeding continues for one year and that reproduction occurs the following year from May to August. Lampreys are considered to be semelparous, i.e., reproducing only once before dying.

Population Sizes and Trends

Population size estimates for Vancouver Lamprey come from local experts (1000-2000 adults) and genetic data (65 to >2971 adults). However, more accurate estimates (e.g., from mark-recapture studies) are still needed. A small number of trapping studies suggest a decrease in lamprey numbers in 2008 compared to the 1980s, but these studies are not directly comparable. Genetic data do not indicate any recent population bottlenecks. Although rates of lamprey scarring on salmonids fluctuate, it is difficult to draw conclusions about lamprey abundance from scarring data, as scarring rates will also be affected by salmonid population fluctuations.

Threats and Limiting Factors

Vancouver Lamprey, given its restricted distribution, is vulnerable to localized changes in habitat or other localized threats. Vancouver Lamprey habitat is threatened by droughts, dams and water management, increased sedimentation due to forestry, and residential development. As well, bycatch of Vancouver Lamprey adults in the recreational fishery may have an adverse effect on the adult population. The population size of Vancouver Lamprey is limited by its restricted distribution, the availability of food, and its reduced genetic diversity.

Protection, Status and Ranks

Vancouver Lamprey was designated by COSEWIC as Special Concern in 1986, and this status was re-examined and confirmed in April 1998. Status was re-examined and designated Threatened in November 2000 and November 2008. Vancouver Lamprey is red-listed (i.e., extirpated, endangered, or threatened in British Columbia) by the BC government. It is protected under the federal *Species at Risk Act* (SARA) as a Schedule 1 Species. NatureServe considers it to be imperilled to critically imperilled on global, national, and provincial scales.

TECHNICAL SUMMARY

Entosphenus macrostomus

Vancouver Lamprey

Lamproie de Vancouver

Range of occurrence in Canada (province/territory/ocean): British Columbia – Endemic to Vancouver Island

Demographic Information

Generation time (usually average age of parents in the population; indicate if another method of estimating generation time indicated in the IUCN guidelines (2011) is being used)	7 to 8 years
Is there an [observed, inferred, or projected] continuing decline in number of mature individuals?	Unknown. Trapping studies conducted in the 1980s versus 2008 suggest a possible decline, but these studies are not directly comparable (*see* “Fluctuations and Trends”). Genetic data do not indicate any recent population bottlenecks (*see* “Fluctuations and Trends”).
Estimated percent of continuing decline in total number of mature individuals within [5 years or 2 generations]	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over the last [10 years, or 3 generations].	Unknown
[Projected or suspected] percent [reduction or increase] in total number of mature individuals over the next [10 years, or 3 generations].	Unknown
[Observed, estimated, inferred, or suspected] percent [reduction or increase] in total number of mature individuals over any [10 years, or 3 generations] period, over a time period including both the past and the future.	Unknown
Are the causes of the decline a.clearly reversible and b.understood and c. ceased?	Not applicable
Are there extreme fluctuations in number of mature individuals?	Unknown. Fluctuations of greater than one order of magnitude might be inferred from the number of juveniles caught in the downstream salmon enumeration trap in Mesachie Creek; however, Mesachie Lake is much smaller than Cowichan Lake and presumably contains a much smaller proportion of the lamprey population. Changes in salmonid scarring rates suggest that lamprey populations fluctuate, but this is complicated by fluctuations in salmonid populations, and scarring rates cannot be used to estimate lamprey abundance (*see* “Fluctuations and Trends”).

Extent and Occupancy Information

Estimated extent of occurrence (EOO)	176 km^2 (set to IAO – see text)
Index of area of occupancy (IAO) (Always report 2x2 grid value).	176 km^2
Is the population "severely fragmented" i.e., is >50% of its total area of occupancy in habitat patches that are (a) smaller than would be required to support a viable population, and (b) separated from other habitat patches by a distance larger than the species can be expected to disperse?	a. No b. No
Number of "locations"* (use plausible range to reflect uncertainty if appropriate)	1–3. There is uncertainty about the degree of movement between Cowichan, Bear, and Mesachie lakes, although it is likely that at least some movement occurs (*see* "Intraspecific Population Structure", "Designatable Units", and "Dispersal and Migration"). Some threats (droughts, dams and water management) are likely to affect the Cowichan Lake system as a whole; other threats (increased sedimentation from forestry, residential development, bycatch of adults) may have different effects in different lakes (*see* "Number of Locations").
Is there an [observed, inferred, or projected] decline in extent of occurrence?	No
Is there an [observed, inferred, or projected] decline in index of area of occupancy?	No
Is there an [observed, inferred, or projected] decline in number of subpopulations?	Not applicable. Vancouver Lamprey only occurs in Cowichan, Bear, and Mesachie lakes.
Is there an [observed, inferred, or projected] decline in number of "locations"*?	No
Is there an [observed, inferred, or projected] decline in [area, extent and/or quality] of habitat?	Yes. Habitat loss or alteration is likely due to droughts, dams and water management, increased sedimentation due to forestry, and residential development
Are there extreme fluctuations in number of subpopulations?	Not applicable
Are there extreme fluctuations in number of "locations"∗?	No
Are there extreme fluctuations in extent of occurrence?	No
Are there extreme fluctuations in index of area of occupancy?	No

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

Number of Mature Individuals (in each subpopulation)

Subpopulations (give plausible ranges)	N Mature Individuals
Cowichan, Bear, and Mesachie lakes	Abundance has been estimated by a local expert (1000-2000 adults) and from genetic data (65 to >2971 adults). These estimates are all uncertain (*see* “Abundance”, below).
Total	

Quantitative Analysis

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

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

Was a threats calculator completed for this species? Yes

i. Droughts (threat 11.2, impact Medium-Low)
ii. Dams and water management (threat 7.2, impact Medium-Low)
iii. Increased sedimentation due to forestry (threat 9.3, impact Low)
iv. Bycatch of Vancouver Lamprey adults (threat 5.4 impact Low)
v. Residential development (threat 1.1 impact Low)

What additional limiting factors are relevant? Vancouver Lamprey are limited by their restricted distribution, the availability of food (i.e., their hosts), and their reduced genetic diversity.

Rescue Effect (immigration from outside Canada)

Status of outside population(s) most likely to provide immigrants to Canada.	Not applicable.
Is immigration known or possible?	No
Would immigrants be adapted to survive in Canada?	Not applicable
Is there sufficient habitat for immigrants in Canada?	Not applicable
Are conditions deteriorating in Canada?[+]	Not applicable
Are conditions for the source population deteriorating?[+]	Not applicable
Is the Canadian population considered to be a sink?[+]	Not applicable
Is rescue from outside populations likely?	No

Data Sensitive Species

Is this a data sensitive species? No

Status History

COSEWIC Status History: Designated Special Concern in April 1986. Status re-examined and confirmed in April 1998. Status re-examined and designated Threatened in November 2000, in November 2008, and in November 2017.

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

Status and Reasons for Designation:

Status: Threatened	**Alpha-numeric codes:** Meets Endangered, B1ab(iii)+2ab(iii), but designated Threatened, B1ab(iii)+2ab(iii), because the species is not at imminent risk of extinction.
Reasons for designation: This endemic parasitic fish is known from only three connected lakes and the lower reaches of larger tributaries within a single watershed on Vancouver Island. The species' spawning areas and juvenile rearing habitats have a restricted distribution in tributary deltas and lakeshore littoral habitat. Slow but ongoing declines in habitat quality and quantity due to threats from droughts and water management, sediment mobilized following upslope logging, and shoreline development threaten the species' long-term persistence.	

Applicability of Criteria

Criterion A (Decline in Total Number of Mature Individuals): Not applicable
Criterion B (Small Distribution Range and Decline or Fluctuation): Meets Endangered, B1ab(iii)+2ab(iii), since the EOO and IAO are below the threshold, there are less than 5 locations, and there is a projected decline in quantity and quality of habitat.
Criterion C (Small and Declining Number of Mature Individuals): Not applicable
Criterion D (Very Small or Restricted Population): Not applicable
Criterion E (Quantitative Analysis): Not applicable

PREFACE

Vancouver Lamprey was originally assessed as Special Concern in 1986, and this status was maintained in 1998. It was reassessed as Threatened in 2000 and 2008. The scientific name of Vancouver Lamprey has recently been changed from *Lampetra macrostoma* to *Entosphenus macrostomus*.

Since the 2008 status assessment, habitat use and distribution of Vancouver Lamprey have been better described. Ammocoetes were found to be widely distributed throughout Cowichan, Bear, and Mesachie lakes, particularly near the mouths of tributaries. Ammocoetes were present in a variety of substrate types, but medium-fine to fine substrate and organic debris may be particularly important. Available habitat has also been better characterized in Cowichan Lake, indicating the relative rarity of the important stream mouth habitat (4.6% of shoreline).

In 2012, the first study of Vancouver Lamprey genetic population structure indicated that Vancouver Lamprey and other freshwater parasitic lampreys on the Sechelt Peninsula each arose independently from Pacific Lamprey. Vancouver Lamprey was also distinct from Pacific Lamprey in the Cowichan River, and genetic diversity was lower in Vancouver Lamprey than in anadromous Pacific Lamprey. Comparison of Vancouver Lamprey from different sites within Cowichan and Mesachie lakes indicated low to moderate (but often significant) genetic differentiation among sites, with no clear geographic patterns. Cowichan and Mesachie lakes were somewhat distinct from each other but not reciprocally monophyletic; further study will be necessary to determine whether any population sub-structuring occurs. In this report, the data from the 2012 study were used to create estimates of Vancouver Lamprey abundance and to test for recent population bottlenecks.

Population trends and threats to Vancouver Lamprey are somewhat better understood than in the 2008 status report. Trapping studies suggest that the number of Vancouver Lamprey adults may have decreased since the 1980s, but studies conducted in 2008 versus the 1980s are not directly comparable, and genetic data do not indicate any recent population bottlenecks. The previous status report indicated that a decline in the Coho Salmon population was a threat to Vancouver Lamprey; however, it now appears that Coastal Cutthroat Trout are a more important prey source. A recent drought in the Cowichan Valley region has lowered summer lake levels and caused seasonal exposure of stream mouth areas. In combination with pumping of water over the Cowichan Lake weir, this may threaten lamprey spawning and rearing habitat. Increased sedimentation due to forestry may also decrease habitat availability. Bycatch of Vancouver Lamprey adults in the recreational fishery remains a concern, but the impact on the population is likely low. There is increasing development along the shorelines of Cowichan and Mesachie lakes; however, the impact of this development on Vancouver Lamprey habitat has not yet been directly assessed.

COSEWIC HISTORY

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created in 1977 as a result of a recommendation at the Federal-Provincial Wildlife Conference held in 1976. It arose from the need for a single, official, scientifically sound, national listing of wildlife species at risk. In 1978, COSEWIC designated its first species and produced its first list of Canadian species at risk. Species designated at meetings of the full committee are added to the list. On June 5, 2003, the *Species at Risk Act* (SARA) was proclaimed. SARA establishes COSEWIC as an advisory body ensuring that species will continue to be assessed under a rigorous and independent scientific process.

COSEWIC MANDATE

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assesses the national status of wild species, subspecies, varieties, or other designatable units that are considered to be at risk in Canada. Designations are made on native species for the following taxonomic groups: mammals, birds, reptiles, amphibians, fishes, arthropods, molluscs, vascular plants, mosses, and lichens.

COSEWIC MEMBERSHIP

COSEWIC comprises members from each provincial and territorial government wildlife agency, four federal entities (Canadian Wildlife Service, Parks Canada Agency, Department of Fisheries and Oceans, and the Federal Biodiversity Information Partnership, chaired by the Canadian Museum of Nature), three non-government science members and the co-chairs of the species specialist subcommittees and the Aboriginal Traditional Knowledge subcommittee. The Committee meets to consider status reports on candidate species.

DEFINITIONS
(2017)

Wildlife Species	A species, subspecies, variety, or geographically or genetically distinct population of animal, plant or other organism, other than a bacterium or virus, that is wild by nature and is either native to Canada or has extended its range into Canada without human intervention and has been present in Canada for at least 50 years.
Extinct (X)	A wildlife species that no longer exists.
Extirpated (XT)	A wildlife species no longer existing in the wild in Canada, but occurring elsewhere.
Endangered (E)	A wildlife species facing imminent extirpation or extinction.
Threatened (T)	A wildlife species likely to become endangered if limiting factors are not reversed.
Special Concern (SC)*	A wildlife species that may become a threatened or an endangered species because of a combination of biological characteristics and identified threats.
Not at Risk (NAR)**	A wildlife species that has been evaluated and found to be not at risk of extinction given the current circumstances.
Data Deficient (DD)***	A category that applies when the available information is insufficient (a) to resolve a species' eligibility for assessment or (b) to permit an assessment of the species' risk of extinction.

* Formerly described as "Vulnerable" from 1990 to 1999, or "Rare" prior to 1990.

** Formerly described as "Not In Any Category", or "No Designation Required."

*** Formerly described as "Indeterminate" from 1994 to 1999 or "ISIBD" (insufficient scientific information on which to base a designation) prior to 1994. Definition of the (DD) category revised in 2006.

Environment and Climate Change Canada / Environnement et Changement climatique Canada
Canadian Wildlife Service / Service canadien de la faune

Canada

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

COSEWIC Status Report

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Entosphenus macrostomus

in Canada

2017

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WILDLIFE SPECIES DESCRIPTION AND SIGNIFICANCE

Name and Classification

Kingdom: Animalia

Phylum: Chordata

Class: Petromyzontida

Order: Petromyzontiformes

Family: Petromyzontidae

Scientific name: *Entosphenus macrostomus* (Beamish 1982)

Synonym: *Lampetra macrostoma* Beamish 1982. Previously, *Entosphenus* was considered as a subgenus within the genus *Lampetra* (e.g., Hubbs and Potter 1971), although some authors classified it as a distinct genus (e.g., Vladykov and Kott 1979). Morphological (Gill *et al.* 2003) and genetic (Beamish and Withler 1986; Docker *et al.* 1999) evidence suggested that *Entosphenus* was sufficiently distinct to be considered a separate genus (*see* Potter *et al.* 2015). Nelson (2006) recognized *Entosphenus* as a valid genus, making *Entosphenus macrostomus* the scientific name of Vancouver Lamprey. This change was confirmed in the most recent edition of the Common and Scientific Names of Fishes from the United States, Canada, and Mexico (Page *et al.* 2013). Although many documents still refer to Vancouver Lamprey as *Lampetra macrostoma*, this status report will conform to Page *et al.* (2013) and use the scientific name *Entosphenus macrostomus*.

Common name: English: Vancouver Lamprey (Page *et al.* 2013)
Other: Lake Lamprey, Cowichan Lake Lamprey, Cowichan Lamprey
French: Lamproie de Vancouver (Page *et al.* 2013)
Other: Lamproie de lac, Lamproie du lac Cowichan

Vancouver Lamprey was initially believed to be a dwarf race of Pacific Lamprey (*Entosphenus tridentatus*) that either spent one year in fresh water prior to going to sea or was landlocked (*see* Beamish 1985). It was described as a distinct species (Beamish 1982) on the basis of morphological and physiological differences (*see* “Morphological Description,” below) and differences in spawning time and location that would likely lead to reproductive isolation (*see* “Interactions with Pacific Lamprey,” below).

Docker *et al.* (1999) compared 735 base pairs (bp) of mitochondrial DNA sequence in Vancouver and Pacific lampreys and found the two species to be genetically indistinguishable at these two genes (cytochrome b and ND3 genes). Subsequent mitochondrial DNA sequence efforts have likewise not revealed diagnostic differences between Vancouver and Pacific lampreys. Lang *et al.* (2009) sequenced 1,133 bp of the cytochrome b gene in one Vancouver Lamprey specimen, which differed by 0–0.18% from cytochrome b gene sequence in 11 Pacific Lamprey (Lang *et al.* 2009; Boguski *et al.* 2012), that is, variation between Vancouver and Pacific lampreys was the same as that observed intra-specifically in Pacific Lamprey. The cytochrome oxidase subunit I (COI) gene (the "DNA barcode" gene) has not been sequenced in Vancouver Lamprey (Hubert *et al.* 2008; April *et al.* 2011). A lack of diagnostic differences observed to date in the mitochondrial genome suggests recent divergence between these two species, i.e., that Vancouver Lamprey is a recent freshwater derivative of the anadromous Pacific Lamprey. Docker *et al.* (1999) approximated that divergences more recent than 70,000 years could not be detected with the sequence data they examined, and Beamish (1982) suggested that Cowichan Lake drainage patterns changed about 10,000 years ago, resulting in reproductive isolation of the *E. macrostomus* lineage from sea-run *E. tridentatus* in the Strait of Georgia. Although the other presumptive *E. tridentatus* derivatives, the Klamath Lamprey (*E. similis*) and Miller Lake Lamprey (*E. minimus*), were genetically distinct from anadromous *E. tridentatus* (Docker *et al.* 1999), the Pit-Klamath Brook Lamprey (*E. lethophagus*) from California was also genetically indistinguishable from *E. tridentatus* (Docker *et al.* 1999) and a lack of fixed mitochondrial DNA sequence differences between closely related lamprey species is common (e.g., Docker *et al.* 1999; Lorion *et al.* 2000; Espanhol *et al.* 2007; Mateus *et al.* 2011; Docker *et al.* 2012). Despite the lack of fixed cytochrome b sequence differences in Vancouver and Pacific lampreys, however, Taylor *et al.* (2012) demonstrated significant differences in microsatellite allele frequencies. Genetic divergence (measured as F_{ST}) between Vancouver Lamprey and Pacific Lamprey from the nearby Cowichan River (range 0.016 to 0.072, average 0.046) was approximately four times greater than F_{ST} between Pacific Lamprey from the Cowichan River and from the Nass River (range 0.008 to 0.014, average 0.012) approximately 800 km away. Furthermore, Vancouver Lamprey grouped separately from Cowichan River (and Nass River) Pacific Lamprey on a neighbour-joining tree (Taylor *et al.* 2012). This suggests that Vancouver and Pacific lampreys represent distinct gene pools.

There are reports of other parasitic, freshwater *E. tridentatus*-like lampreys in at least three other (disjunct) locales in southwestern British Columbia, including on Quadra and Nelson islands (Beamish 1982) and on the Sechelt Peninsula (Taylor *et al.* 2012; *see* "Population Spatial Structure and Variability," below), suggesting either that Vancouver Lamprey has a broader distribution than previously thought or that these freshwater derivatives evolved independently. Genetic evidence by Taylor *et al.* (2012) supports separate evolution of the freshwater parasitic phenotype on the Sechelt Peninsula and in the Cowichan Lake drainage (*see* "Population Spatial Structure and Variability," below), indicating that each is more closely related to Pacific Lamprey than to each other and, hence, do not constitute a single monophyletic taxon. The phylogenetic identity of such recently and independently derived forms is complex (i.e., whether each independently derived freshwater form merits species status), but until further information is available, the other parasitic freshwater-resident forms are referred to as *Entosphenus* sp. and Vancouver Lamprey is known only from three lakes in the Cowichan Valley drainage.

Morphological Description

Vancouver Lamprey has a cylindrical, eel-like, scaleless body with no paired fins. It has seven pairs of gill openings, and its skeleton is cartilaginous. It has a small caudal fin and two distinct dorsal fins (Figure 1).

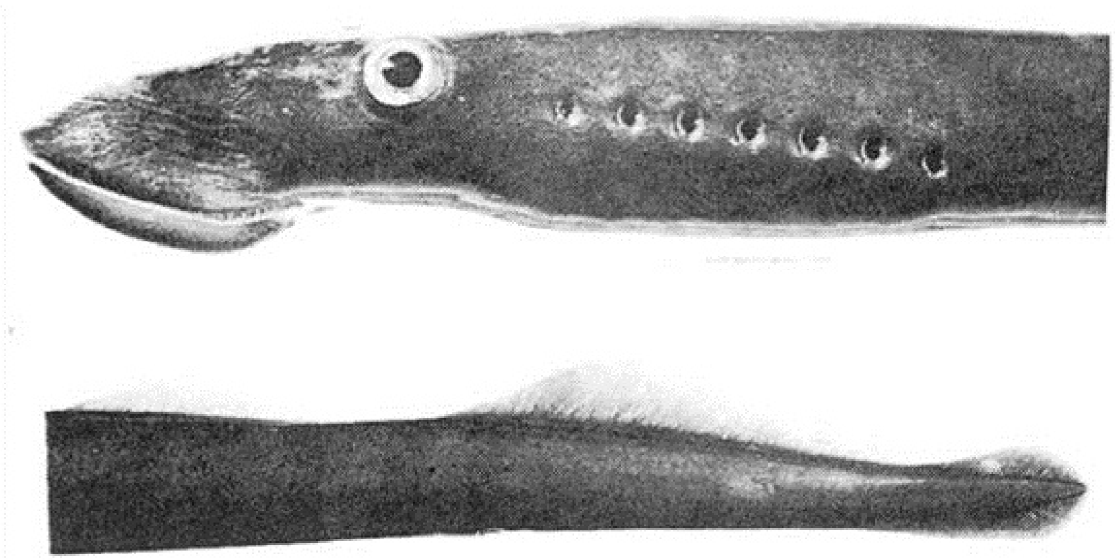

Figure 1. Head and tail regions of a 22.8 cm Vancouver Lamprey *Entosphenus macrostomus* photographed live and captured in Cowichan Lake, November 1980. Photograph by R.J. Beamish (with permission).

The adult is blue-black or dark brown on its dorsal surface, with a lighter ventral surface. It has a round suctorial mouth with many sharp, horny teeth, and the tongue also has many sharp teeth. The eyes are large and located high on the head. Vancouver Lamprey adults range in size from 18 to 27 cm (average 20.6 cm), with females being slightly smaller than males (Beamish 1982). It can be morphologically distinguished from the closely related Pacific Lamprey mostly by the relatively larger size of its oral disc. When a Vancouver Lamprey adult is viewed from above, the diameter of the mouth is noticeably wider than its head, whereas the diameter of the mouth of a Pacific Lamprey adult is not wider than its head or body (McPhail and Carveth 1993). The disc of Vancouver Lamprey has approximately two-thirds more surface area than that of a similar sized Pacific Lamprey, and there are some differences in dentition (Beamish 1982). In addition, Vancouver Lamprey is generally smaller than the Pacific Lamprey; mature Pacific Lamprey range in length from 13 to at least 72 cm (Beamish 1980) and average approximately 54 cm in length (Scott and Crossman 1973). Other morphological differences include a relatively larger eye, longer prebranchial length, and, possibly, a shorter trunk length in Vancouver Lamprey compared to the Pacific Lamprey (Beamish 1982). Internally, the velar tentacles in *E. macrostomus* are very weakly pigmented relative to the darkly pigmented base and lower portion of the velar tentacles of *E. tridentatus* (Beamish 1982). These differences in body proportion are consistent with those found between other recognized lamprey species. For example, the European and Western River lampreys (*Lampetra fluviatilis* and *L. ayresii*, respectively) can be distinguished based on relatively small differences in body proportions (Vladykov and Follett 1958), yet they are genetically very distinct (Docker *et al.* 1999). Physiologically, Vancouver Lamprey also differs from the Pacific Lamprey in its ability to osmoregulate in fresh water throughout its entire life cycle; in contrast, Pacific Lamprey may survive in fresh water for a few months post-metamorphosis but are unable to complete the parasitic feeding phase in fresh water (Beamish 1980; Beamish 1982; Clarke and Beamish 1988).

!As adults, Vancouver Lamprey can be distinguished from the other lampreys found in British Columbia (the Western River and Western Brook lampreys, *Lampetra ayresii* and *L. richardsoni*, respectively) largely by differences in tooth patterns. The supraoral lamina (the tooth bar immediately above the mouth) has three teeth in Vancouver and Pacific lampreys, but only two teeth in the Western River and Western Brook lampreys (*see* McPhail and Carveth 1993).

The larvae, known as ammocoetes, lack teeth and true eyes (possessing instead an “eye spot,” in which the developing eye is encased under a transparent patch of skin), and possess an oral hood rather than the sucking disc characteristic of juvenile and adult lampreys. Ammocoetes may be as large as 17 cm in length (Beamish 1982). No reliable morphological characters have been found to distinguish larval Vancouver and Pacific lampreys (Richards *et al.* 1982), but they can be distinguished from Western River and Western Brook lampreys by differences in pigmentation. In Vancouver and Pacific lamprey ammocoetes, the caudal ridge (a thickening in the tail region formed by the end of the notochord and its overlying tissues) is lightly pigmented and the body and head are extensively pigmented, whereas the tail is darkly pigmented in the caudal ridge area in Western Brook Lamprey ammocoetes; in the Western River Lamprey, both the tail and head regions are lightly pigmented (Richards *et al.* 1982; *see also* McPhail and Carveth 1993). Genetic markers, however, can reliably differentiate Vancouver and Pacific lampreys (i.e., genus *Entosphenus*) from Western River and Western Brook lampreys (i.e., genus *Lampetra*) at any size (Docker *et al.* 2016), although no genetic markers are known that can differentiate between Vancouver and Pacific lampreys (*see* above) or Western River and Western Brook lampreys (Docker *et al.* 1999, Docker 2009).

Population Spatial Structure and Variability

<u>Relationships with other derivatives of Pacific Lamprey</u>

Three additional populations of freshwater *Entosphenus tridentatus*-like lampreys have been reported in British Columbia: 1) from Village Bay Lake on Quadra Island (Beamish 2001); 2) West Lake on Nelson Island (Beamish 2001); and 3) Sakinaw Lake at the north end of the Sechelt Peninsula (Taylor *et al.* 2012). In addition, Vladykov and Kott (1979) described a landlocked lamprey from Cultus Lake, which is located on the mainland approximately 90 km from Vancouver, but its disc size was smaller (Beamish 1982), and its relationship to Vancouver Lamprey is not known. The Quadra Island and Nelson Island populations have not been studied in detail (Beamish 2001; Taylor pers. comm. 2007), although observations suggest that the lamprey on Quadra Island might not be a self-sustaining freshwater-resident population; there are reports of lamprey feeding on the resident trout (Beamish pers. comm. 2015).

The Sechelt Peninsula population has been studied in slightly more detail. Anadromous *E. tridentatus* are found in the Sakinaw Lake system, but a freshwater form which is morphologically different from *E. macrostomus* (Beamish pers. comm. 2008) is also present. Sakinaw Lake supports a Sockeye Salmon (*Oncorhynchus nerka*) population assessed as Endangered by COSEWIC (COSEWIC 2016), and enumerations of Sockeye and Coho (*O. kisutch*) salmon smolts leaving the lake show that 5 and 20% of the smolts, respectively, have been attacked by a freshwater-resident lamprey (Baillie pers. comm. 2007). Taylor *et al.* (2012) examined lamprey larvae from Sakinaw Lake and Ruby Lake (a nearby lake on the Sechelt Peninsula). They found that the cytochrome b sequence of lamprey from this population was identical to that of *E. tridentatus* and *E. macrostomus*. However, when examined using eight microsatellite loci, the Sechelt Peninsula lamprey (*Entosphenus* sp.) and *E. macrostomus* were not reciprocally monophyletic (Figure 2); each was more closely related to anadromous *E. tridentatus* than they were to each other. This suggests that Vancouver Lamprey and Sechelt Peninsula freshwater lamprey each arose independently from *E. tridentatus*.

Other freshwater lampreys that are presumably derivatives of the Pacific Lamprey (e.g., Klamath Lamprey and Miller Lake Lamprey) have been recognized in Oregon and California (Vladykov and Kott 1976; Bond and Kan 1973; Gill *et al.* 2003; *see* “Name and Classification,” above), but they are genetically distinct from the Pacific Lamprey (and therefore also from Vancouver Lamprey).

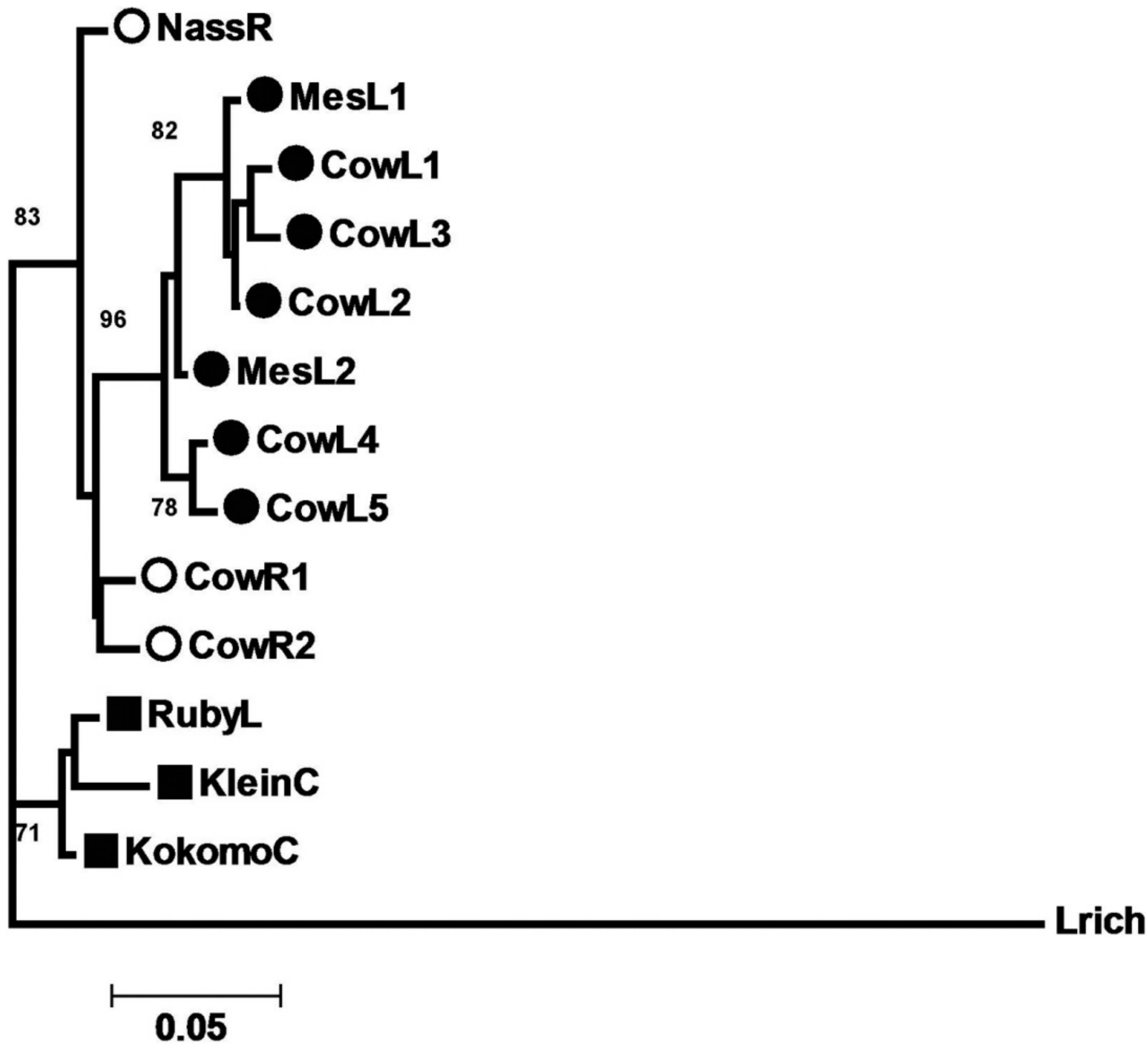

Figure 2. Neighbour-joining tree of pairwise Cavalli-Sforza chord genetic distances generated from assays of eight microsatellite DNA loci in Vancouver Lamprey *Entosphenus macrostomus* and Pacific Lamprey *E. tridentatus*. Numbers at branch points represent bootstrap percentage scores from 100 bootstrap pseudoreplicates. The tree is rooted using samples of Western Brook Lamprey (*Lampetra richardsoni*; "Lrich"). Filled circles indicate *E. macrostomus* samples from Cowichan Lake ("CowL") and Mesachie Lake ("MesL"). Open circles indicate anadromous *E. tridentatus* from Nass River ("NassR") and Cowichan River ("CowR"). Filled squares indicate parasitic freshwater *Entosphenus* sp. from the Sechelt Peninsula ("RubyL", "KleinC", "KokomoC"). From Taylor *et al.* (2012); © 2012 Canadian Science Publishing or its licensors, reproduced with permission.

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Intraspecific population structure

Taylor *et al.* (2012) conducted the only published study of Vancouver Lamprey population structure to date. They sampled Vancouver Lamprey larvae from five sites in Cowichan Lake and two sites in Mesachie Lake (but no sites in Bear Lake). Their study also included three groups of Pacific Lamprey (two groups from Cowichan River and one group from Nass River, British Columbia) and three groups of freshwater parasitic *Entosphenus* sp. from the Sechelt Peninsula (*see* “Relationships with other derivatives of Pacific Lamprey,” above). Sample sizes ranged from 23 to 43 larvae per site. They used eight microsatellite loci to examine population structure in these samples.

Taylor *et al.* (2012) found that genetic differentiation was generally low to moderate (but often significant) within Cowichan and Mesachie lakes. No clear geographic patterns were evident. F_{ST} values ranged from -0.00244 to 0.08833, with an average of 0.04115, and 15 of 21 pairwise comparisons were statistically significant. Based on F_{ST} values, Cowichan and Mesachie lakes did not appear to be genetically distinct from one another; the highest F_{ST} value occurred between two sites within Cowichan Lake, and the lowest F_{ST} value occurred between a Cowichan Lake site and a Mesachie Lake site. Similarly, although Cowichan and Mesachie lakes grouped together on a neighbour-joining tree (i.e., *E. macrostomus* was monophyletic), the lakes were not reciprocally monophyletic (Figure 3). In STRUCTURE analysis, four population clusters were present: two clusters within Cowichan and Mesachie lakes, one cluster including the three populations of anadromous Pacific Lamprey, and one cluster including the three populations of Sechelt Peninsula *Entosphenus* sp. (Figure 4). In STRUCTURE analysis, Cowichan (sites 1–5) and Mesachie (sites 6, 7) lakes appeared to be somewhat distinct from each other; however, these differences are not clear-cut. Morphological data also suggest migration and gene flow between the lakes (*see* “Dispersal and Migration,” below). Further sampling (including more individuals from more sites in Cowichan, Bear, and Mesachie lakes) will be necessary to determine whether population sub-structuring occurs in Vancouver Lamprey.

Taylor *et al.* (2012) found that genetic diversity was lower in Vancouver Lamprey than in anadromous Pacific Lamprey. Levels of heterozygosity (H_O) were similar in Vancouver Lamprey (range 0.45 to 0.54, average 0.50) compared to anadromous Pacific Lamprey (range 0.45 to 0.56, average 0.51). However, allelic richness (AR) was much higher in anadromous Pacific Lamprey (range 4.67 to 4.96, average 4.78) than in Vancouver Lamprey (range 2.83 to 3.33, average 3.04). The reduced genetic diversity observed in Vancouver Lamprey by Taylor *et al.* (2012) is common in freshwater populations compared to anadromous populations (DeWoody and Avise 2000).

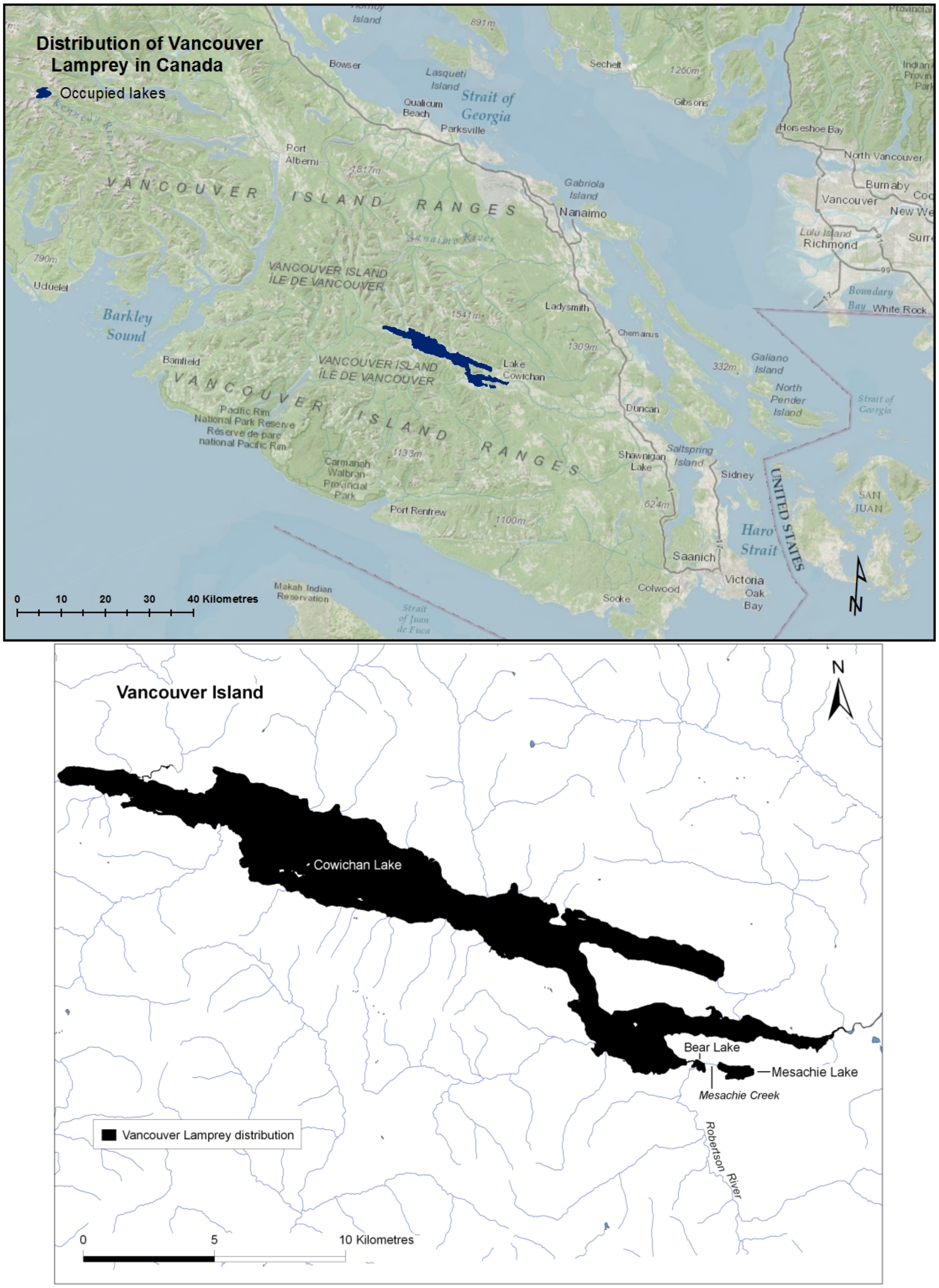

Figure 3. Distribution of Vancouver Lamprey, *Entosphenus macrostomus*, in Cowichan, Bear, and Mesachie lakes. Other freshwater *Entosphenus tridentatus*-like lampreys have been reported in Village Bay Lake, West Lake, and Sakinaw Lake (*see* text, “Distribution”).

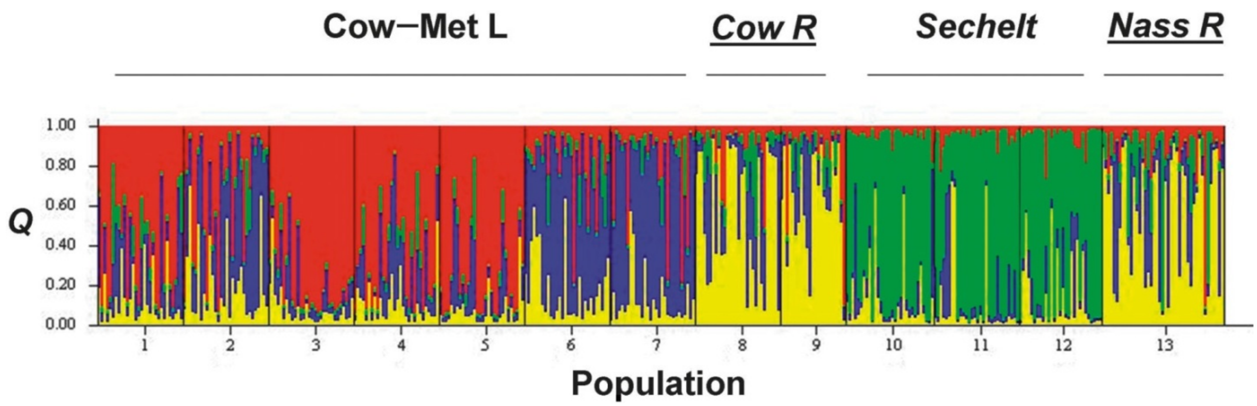

Figure 4. Bar plot indicating admixture coefficient (Q) for individual Vancouver Lamprey *Entosphenus macrostomus* (normal font) and Pacific Lamprey *E. tridentatus* (italic font) assayed at eight microsatellite DNA loci. Localities with anadromous lamprey are underlined. Each individual is represented by a thin vertical line where the height of each of four coloured portions is equal to the proportional contribution of each of four genetic groups (red, yellow, blue, and green). Samples are grouped by sample locality: 1-5, Cowichan Lake and 6-7 Mesachie Lake (*E. macrostomus*); 8-9, Cowichan River (*E. tridentatus*); 10-12, Sechelt Peninsula lakes (parasitic freshwater *Entosphenus* sp.); 13, Nass River (*E. tridentatus*). From Taylor *et al.* (2012); © 2012 Canadian Science Publishing or its licensors, reproduced with permission.

Designatable Units

Vancouver Lamprey is distinct from the closely related Pacific Lamprey in terms of morphology (Beamish 1982; *see* “Morphological Description,” above), life history (Beamish 1982; *see* “Physiology and Adaptability” and “Interspecific Interactions,” below), and microsatellite allele frequency (Taylor *et al.* 2012; *see* “Name and Classification,” above). Freshwater derivatives of anadromous species are common in lampreys (Docker 2009) and other north temperate fishes (Taylor 1999), but Vancouver Lamprey is formally recognized as a distinct species and not a freshwater form of Pacific Lamprey (Beamish 1982; Page *et al.* 2013). The morphological, physiological, and genetic differences noted between Vancouver and Pacific lampreys are consistent with those found between other recognized lamprey species, and Vancouver Lamprey is clearly a separate designatable unit, distinct from Pacific Lamprey.

Vancouver Lamprey is also thought to be distinct from other freshwater parasitic lampreys derived from Pacific Lamprey (*see* “Relationships with other derivatives of Pacific Lamprey,” above). The Sechelt Peninsula population, in particular, is both morphologically (Beamish pers. comm. 2008) and genetically (Taylor *et al.* 2012) different from Vancouver Lamprey. The Cultus Lake population lacks the distinctively large oral disc of Vancouver Lamprey (Beamish 1982), and the Quadra Island and Nelson Island populations have not been studied in detail (Beamish 1982; Taylor pers. comm. 2007). Genetic study of the Cultus Lake, Quadra Island, and Nelson Island populations would be beneficial; however, at present it appears that Vancouver Lamprey occurs only in Cowichan, Bear, and Mesachie lakes on southern Vancouver Island, British Columbia (Beamish 1982).

Within these lakes, there is a question of how many designatable units are present. Juveniles (i.e., post-metamorphosis but prior to full sexual maturity) and adults (sexually mature individuals; *see* “Life Cycle and Reproduction,” below) have also been caught in the creek connecting Bear and Mesachie lakes (Mesachie Creek). These captures were largely (n = 336) in the downstream traps of a salmon enumeration fence operated between 1988 and 1996, but six lamprey were caught in the upstream trap (Beamish and Wade 2008; *see* “Distribution,” below). This suggests gene flow between Bear and Mesachie lakes; however, Beamish (pers. comm. 2016) states that upstream movement is more questionable, and the lamprey caught in the upstream traps may have simply been seeking shelter. Further research will be required to determine whether there is asymmetry in movement between Bear and Mesachie lakes (and, if so, the degree of asymmetry and its effects). It is also possible that parasitic feeding phase lamprey may be transported among lakes while attached to host fish; however, there do not appear to be any records of this occurring.

Genetic data suggest some degree of migration among lakes. The genetic differentiation found between Cowichan and Mesachie lakes by Taylor *et al.* (2012) was relatively small, with F_{ST} values indicating low to moderate differentiation (*see* “Population Spatial Structure and Variability,” above). Similarly, sites from the two lakes did not cluster separately on a neighbour-joining tree. Although the STRUCTURE analysis suggested that there may be some genetic differentiation between Cowichan and Mesachie lakes, the lakes were not completely distinct. Taylor *et al.* (2012) sampled only a small number of sites within the Cowichan-Mesachie Lake system; a more thorough sampling of sites, especially including a better representation of Cowichan and Bear lakes, would be necessary before drawing firm conclusions.

It appears that some migration occurs between Bear and Mesachie lakes, and the genetic differences between Cowichan and Mesachie lakes are small. Migration between Cowichan and Bear lakes has not been directly assessed, but the channel connecting these two lakes is present year-round, so movement is presumably possible. There is, therefore, insufficient evidence to suggest the existence of more than one designatable unit under the COSEWIC Guidelines for Recognizing Designatable Units (COSEWIC 2015).

Special Significance

Vancouver Lamprey is a recognized species (Page *et al.* 2013). Notwithstanding the taxonomic complications of multiple allopatric occurrences of parasitic freshwater derivatives of the Pacific Lamprey discussed by Taylor *et al.* (2012), Vancouver Lamprey is differentiated from Pacific Lamprey in terms of genetic, morphological, physiological, and life history traits.

Vancouver Lamprey is significant for several reasons. It is one of only a few freshwater fish species endemic to Canada, where it is known to occur in only three interconnected lakes on southern Vancouver Island. During its adult stage, it feeds parasitically on salmonids. Nothing is known about predation on Vancouver Lamprey, but other lamprey species are prey for fish, birds, and mammals (Docker *et al.* 2015; *see*

"Interactions with other species," below). Regarding the cultural value of Vancouver Lamprey to Aboriginal Peoples in Canada, elders for the Cowichan Tribes report that there is a word for the lamprey in their language but no stories or legends around them (Elliott pers. comm. 2007); no other information regarding Aboriginal Traditional Knowledge was found. Public opinion of Vancouver Lamprey is unfortunately often negative, due to Vancouver Lamprey parasitism on sportfish (Vancouver Lamprey Recovery Team 2007; *see* "Threats," below). However, there have been some recent attempts to improve public opinion (Cowichan Watershed Board 2011; BC Local News 2016; Local News Eye 2016).

The special significance of Vancouver Lamprey also includes its scientific value. Like many other fish species of postglacial origin, lampreys show considerable life history variation (i.e., adult lampreys may be parasitic and anadromous, parasitic and freshwater-resident, or nonparasitic and freshwater-resident), and the evolution of life history type is of great scientific interest (reviewed in Docker 2009). The freshwater parasitic and nonparasitic life history types have arisen repeatedly and independently in most lamprey taxa, and this may represent one of the most dramatic cases of parallel evolution in any vertebrate (Mayden pers. comm. 2007). Vancouver Lamprey can provide insights into evolutionary processes in lampreys (e.g., the rate at which the ability to osmoregulate in fresh water throughout the life cycle can evolve in lampreys) and in general (e.g., using molecular genetic dating to estimate the rate at which speciation can occur). Vancouver Lamprey and other freshwater derivatives of Pacific Lamprey (*see* "Name and Classification" and "Population Spatial Structure and Variability," above) may provide insight into the repeated evolution of different life history types (particularly freshwater-resident parasitic forms) in lampreys (Docker 2009). That Vancouver Lamprey spawn and rear in both lakes and lower reaches of streams is also of scientific interest since other related species are thought to primarily spawn and rear in streams.

DISTRIBUTION

Global Range

This species is found only in Canada (*see* "Canadian Range" below).

Canadian Range

Vancouver Lamprey is endemic to Canada and is found only in Cowichan, Bear, and Mesachie lakes on southern Vancouver Island, British Columbia (Figure 3), and the lower part of tributaries flowing into these lakes (Beamish 1982). Vancouver Lamprey has not been observed below the lake outlets (Beamish 1982), even though there are no physical barriers in these lakes that prevent access to the sea. Vancouver Island is part of the Pacific Islands Freshwater Biogeographic Zone.

Cowichan and Mesachie lakes are adjacent and connected via Bear Lake (which is an embayment of Cowichan Lake, rather than a separate waterbody, and is connected to Cowichan Lake by a slow-moving channel) and Mesachie Creek (which connects Bear and Mesachie lakes. The Robertson River flows into Bear Lake (Baillie pers. comm. 2007). Mesachie Lake has two tributary streams: Halfway Creek, which flows into the east end of Mesachie Lake, and Mill Creek, which is an intermittent stream that flows into the southwest end of the lake (Beamish and Wade 2008). Cowichan Lake has multiple tributary streams (Beamish and Wade 2008), most of which (72%) are intermittent (British Columbia Conservation Foundation 2012). Several recent surveys (Harris 2007; Beamish and Wade 2008; Wade and MacConnachie 2016) found ammocoetes widely distributed throughout the Cowichan-Mesachie lake system, particularly near the mouths of tributaries (*see* “Habitat Requirements,” below). Specific locations are discussed in the following paragraph.

Because Mesachie Creek dries up or has only reduced intermittent flow during the summer (Beamish and Wade 2008), it does not provide suitable habitat for lamprey ammocoetes. Beamish (2001) reported that no lamprey have been found in Mesachie Creek, and Harris (2007) found only a single ammocoete there, despite electrofishing the entire length of the creek from Bear Lake to Mesachie Lake. However, traps for Coho Salmon in Mesachie Creek between 1988 and 1996 captured lamprey (primarily post-metamorphic individuals in downstream traps) swimming in the creek. Captures were documented by Beamish and Wade (2008) for 342 lamprey, and in more detail in COSEWIC (2008) for a subset of 225 of these individuals using field records provided by S. Baillie (pers. comm. 2007; Table 1, Figure 5; *see* “Population Sizes and Trends,” below). Numerous ammocoetes have been captured in Bear Lake at the mouth of the Robertson River (Harris 2007). No ammocoetes were collected in the channel that connects Bear Lake to Cowichan Lake, but very few sites were electrofished in this channel given the depth and method of collection (Harris 2007; *see* “Habitat,” below). Minnow traps in Bear Lake captured two fish with lamprey scars, suggesting that adult Vancouver Lamprey may feed in Bear Lake (Harris 2007).

There is no information to suggest that there have been changes in the distribution of this species (i.e., any expansions or contractions of its range) since its description in 1982.

Table 1. Data from the downstream trap of the Mesachie Creek salmon enumeration fence, operated from 1987 to 1996. Wounding information refers to smolts wounded by lamprey (multiple = 2-6 wounds per fish; light = small wounds that are largely healed; moderate = larger wounds that are mostly healed; severe = open wounds that expose flesh or viscera) (data from Baillie pers. comm. 2007; COSEWIC 2008).

							Wound severity (%)			
Year	Dates of fence operation	Number of lamprey	Number of smolts	Number wounded	Percent wounded	Number of wounded smolts assessed	Multiple wounds	Light	Moderate	Severe
1987	May 30 – June 2	0	1,845	629	34.1	629	20.3			
1988	Apr 20 – June 27	17	6,865	810	11.8	391	22.3	33	30.1	36.8

							Wound severity (%)			
Year	Dates of fence operation	Number of lamprey	Number of smolts	Number wounded	Percent wounded	Number of wounded smolts assessed	Multiple wounds	Light	Moderate	Severe
1989	Apr 7 – June 7	7	1,580	139	8.8	121	16.5	23.9	32.1	44
1990	Apr 9 – June 13	22	3,486	987	28.3	266	34.3	38	23	39
1991	Apr 25 – June 5	4	10,654	1183	11.1	188	21.8			
1992	Apr 16 – June 15	21	3,139	229	7.3					
1993	Apr 13 – June 30	51	6,338	919	14.5					
1994	Apr 4 – June 23	12	1,711	392	22.9					
1995	Apr 5 – May 30	60	1,491	376	25.2					
1996	Apr 23 – June 19	31	6,629	1982	29.9					

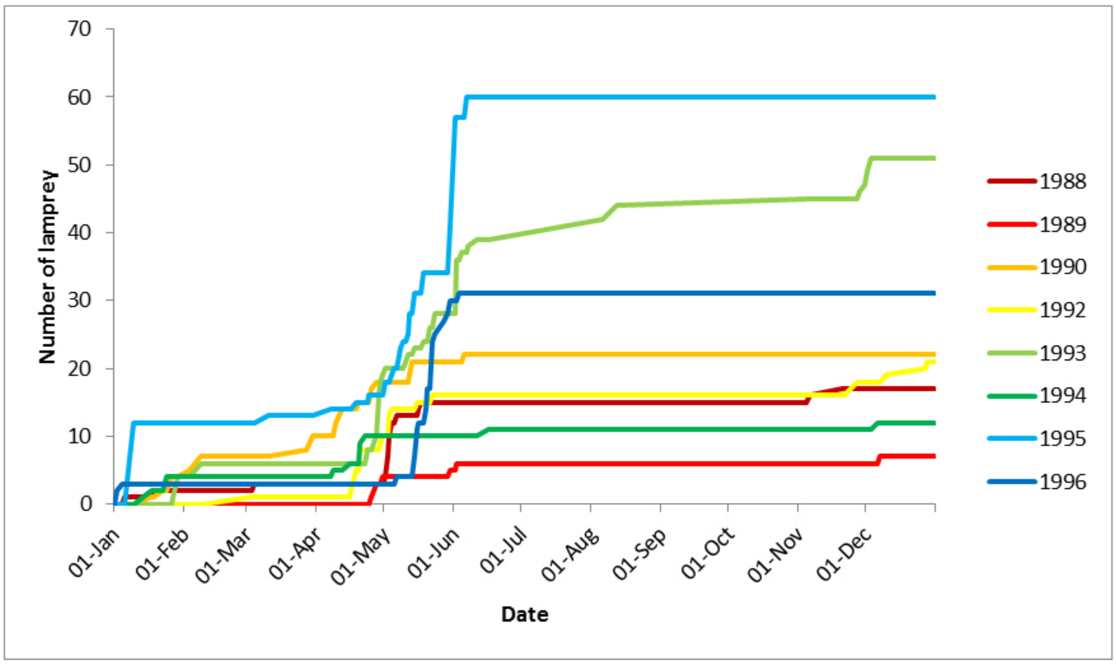

Figure 5. Cumulative number of lamprey collected in the downstream trap at the Mesachie Creek enumeration fence in 1988-1990 and 1992-1996. Only four lamprey were caught in 1991. The fence was not operated from approximately July to September each year, and operation ceased on June 19, 1996 (data from Baillie pers. comm. 2007; COSEWIC 2008).

Extent of Occurrence and Area of Occupancy

The known distribution of Vancouver Lamprey is very limited. Cowichan Lake is approximately 34 km long with a surface area of 6204 ha (62 km^2) (BC Lake Stewardship Society 2005), and Mesachie Lake is only 2.7 km long with a surface area of 59 ha (0.6 km^2) (Beamish 2001); size estimates for Bear Lake are not available, but it is smaller than Mesachie Lake. Although ammocoetes have also been found in the streams that flow into Cowichan Lake, few have been found at distances greater than 100 m upstream from the lake (Beamish 1982). However, relatively limited surveys of tributaries have been conducted, and it is possible that ammocoetes might be present further upstream (Wade pers. comm. 2016).

The known distribution of this species, therefore, is restricted to approximately 63 km^2. Extent of occurrence (EOO) was calculated using the minimum convex polygon method, with two variations: a) calculations based on the boundaries of Cowichan, Bear, and Mesachie lakes, and b) calculations including a 100 m buffer around the edges of these lakes to account for the occasional occurrence of Vancouver Lamprey in the first 100 m of tributaries (*see* “Habitat”, below). EOO values were 120 km^2 and 126 km^2, respectively. But because this estimate of EOO is less than the estimate of IAO calculated with a 2X2 km grid of 176 km^2 (see below), EOO is set at 176 km^2.

Index of area of occupancy (IAO) was calculated using a 2 x 2 km grid, with the same variations as for EOO. IAO was 176 km^2 in both cases. However, the actual AO for Vancouver Lamprey would be approximately equal to the surface area of the three lakes (i.e., approximately 65 km^2) because it appears that a large part of each lake – at least in terms of surface area – is utilized when all stages are included (*see* “Habitat Requirements,” below). But if information was available for the area used for spawning and/or rearing, IOA would likely be substantially smaller.

Search Effort

Search efforts for Vancouver Lamprey have generally not been well quantified; most documented efforts do not fully describe locations surveyed, numbers of lamprey collected or observed, and/or catch per unit effort. Search efforts are summarized in Table 2.

Table 2. Summary of search effort and collections of Vancouver Lamprey *Entosphenus macrostomus*.

Reference	Date of search	Life stage targeted	Method of search	Waterbody	Site	Units of effort	Search results
Beamish (1982)	1980	Parasitic feeding phase	Seines, nets, and traps; caught attached to fish	Cowichan Lake		Not specified	1 parasitic feeding phase lamprey captured
Beamish (1982)	1979	Parasitic feeding phase	Seines, nets, and traps; caught attached to fish	Mesachie Lake		Not specified	16 parasitic feeding phase lamprey captured

Reference	Date of search	Life stage targeted	Method of search	Waterbody	Site	Units of effort	Search results
Beamish (1982)	1980	Mature adults	Traps	Mesachie Lake	Mouth of Halfway Creek	Not specified	94 mature adults captured
Beamish (1982)	1979	Ammocoetes and transformers	Backpack electrofishing	Cowichan and Mesachie lakes	Shorelines	Not specified	Ammocoetes and transformers found; number not specified. Retained 17 transformers and 16 ammocoetes, all from Mesachie Lake, for further study.
Beamish (1982)	1980	Ammocoetes	Backpack electrofishing	Cowichan Lake	Shorelines	Not specified	227 ammocoetes captured
Harris (2007)	2007 (May to August)	Ammocoetes	Backpack electrofishing	Cowichan, Bear, and Mesachie lakes; Mesachie Creek	10 sites along shoreline and near mouths of tributaries	Not specified; for each site, electrofishing was discontinued after 30 ammocoetes were captured	Ammocoetes were present at 16 sites and absent at six. A total of 309 ammocoetes were captured, numbers ranging from 1 to 30 per site.
Harris (2007)	2007 (May to August)	Parasitic feeding phase	Traps	Cowichan, Bear, and Mesachie lakes	9 sites along shoreline and near mouths of tributaries	14 traps; length of time traps were in place was not specified	No lamprey were captured, but some (number not specified) salmonids with lamprey scars were captured.
Harris (2008)	2008 (April to August)	Mature adults	Backpack electrofishing	Cowichan, Bear, and Mesachie lakes	17 tributaries and shorelines in areas with gravel substrate	Not specified	1 adult captured
Harris (2008)	2008 (April to August)	Mature adults	Kick/drift nets	Cowichan, Bear, and Mesachie lakes	17 tributaries	Walked 100-200 m upstream from mouths of tributaries	0 adults captured
Harris (2008)	2008 (April to August)	Mature adults	Fyke nets	Cowichan, Bear, and Mesachie lakes	5 locations along shorelines near tributaries	Nets were checked 1-2 times daily; length of time nets were in use was not specified	4 adults captured in Mesachie Lake
Harris (2008)	2008 (April to August)	Mature adults	Fyke nets	Mesachie Creek		Net was checked 1-2 times daily; length of time net was in use was not specified	1 adult captured
Harris (2008)	2008 (April to August)	Mature adults	Snorkel surveys	Cowichan and Mesachie lakes	Mouths of Halfway, Meades, and Mesachie creeks	Not specified	0 adults captured
Beamish and Wade (2008)	1979 to 1985	Ammocoetes	Backpack electrofishing	Cowichan, Bear, and Mesachie lakes		Not specified	Numbers not specified; ammocoetes found in four sites in Cowichan Lake, one site in Bear Lake, and two sites in Mesachie Lake.
Beamish and Wade (2008)	1982 (May)	Ammocoetes	Boat electrofishing at depths greater than 2m	Mesachie Lake	Mouth of Halfway Creek	3.5 hours	Six ammocoetes and one adult captured

Reference	Date of search	Life stage targeted	Method of search	Waterbody	Site	Units of effort	Search results
Beamish and Wade (2008)	1980	Mature adults	Traps	Mesachie Lake	Mouth of Halfway Creek	Traps used between May 3 and September 18	124 adults captured
Beamish and Wade (2008)	1981	Mature adults	Traps	Mesachie Lake	Mouth of Halfway Creek	Traps used between April 18 and July 25	21 adults captured
Beamish and Wade (2008)	1981	Mature adults	Traps	Bear Lake	Mouth of Robertson River	Traps used between June 9 and July 29	26 adults captured
Beamish and Wade (2008)	1985 to 1988	Ammocoetes and transformers	Backpack electrofishing	Cowichan River		Not specified	0 Vancouver Lamprey captured; Vancouver Lamprey and Pacific Lamprey ammocoetes cannot be distinguished, but all transformers captured were Western Brook Lamprey and Pacific Lamprey.
Beamish and Wade (2008)	1988 to 1996	Ammocoetes and transformers	Incidental capture in traps for Coho Salmon	Mesachie Creek		Not specified	336 lamprey (life stage generally not specified) captured in downstream traps, 6 captured in upstream traps
Beamish and Wade (2008)	2008 (May to June)	Mature adults	Traps	Mesachie Lake	Near Halfway Creek and Mesachie Creek	Not specified	4 adults captured near Halfway Creek, none near Mesachie Creek
Johner and Sebastian (2011)	2010 (July)	Parasitic feeding phase	Incidental capture in trawls for Kokanee	Cowichan Lake	Four trawls in different parts of lake	Four one-hour trawls with a 3 m by 7 m net	6 parasitic feeding phase lamprey captured; 3 in main pool of Cowichan Lake and 3 in south arm
Wade and MacConnachie (2016)	2012 (September)	Ammocoetes	Backpack electrofishing	Cowichan Lake	21 sites along shoreline and in tributaries	Not specified; maximum of 10 minutes of electrofishing time at each location	Ammocoetes present at eight sites and absent at two; habitat found unsuitable at 11 sites. A subsample of 49 ammocoetes were measured, but many more (numbers not given) were captured or sighted.
Wade and MacConnachie (2016)	2012 (September)	Parasitic feeding phase	Incidental capture by anglers	Cowichan Lake		Not specified	Two parasitic feeding phase lamprey captured

Ammocoetes and metamorphosing individuals have generally been sampled using backpack electrofishing in shallow water. Early studies by Beamish (1982) found ammocoetes and transformers distributed along the shorelines of Cowichan and Mesachie lakes. Beamish and Wade (2008) reported finding ammocoetes in four sites in Cowichan Lake, two sites in Mesachie Lake, and one site in Bear Lake; these collections spanned 1979–1985. Similarly, Harris (2007) found ammocoetes in 16 of 22 sites surveyed in Cowichan, Mesachie, and Bear lakes in May to August 2007. Wade and MacConnachie (2016) surveyed 21 sites along the shoreline of Cowichan Lake in 2012. Eleven sites were not electrofished due to unsuitable habitat. Of the remaining sites, lamprey were present at eight sites and absent at two. Taken together, these studies suggest that ammocoetes are widely distributed (but not omnipresent) in shallow water along the shorelines of the Cowichan lake system. In 1982, one attempt at boat electrofishing in deeper water yielded only six ammocoetes and one adult in 3.5 hours (Beamish and Wade 2008).

Parasitic feeding phase lamprey have generally been collected using traps or nets, or via incidental capture by anglers. Using these methods, Beamish (1982) collected 16 feeding phase lamprey from Cowichan Lake and one from Mesachie Lake in 1979 and 1980. Harris (2007) set 14 traps at nine sites within Cowichan, Mesachie, and Bear lakes in the summer of 2007, but failed to capture any lamprey. Wade and MacConnachie (2016) documented capture of two lamprey by anglers in Cowichan Lake in September 2012. However, it seems likely that incidental capture by anglers is much more common than these few documented instances; Beamish and Wade (2008) and M. McCulloch (pers. comm. 2016) reported that local residents sometimes catch fish with lamprey attached, and killing of feeding phase lamprey by anglers is considered a threat to Vancouver Lamprey (Harvey 2015; *see* “Threats,” below).

Mature adults are also usually collected using traps or nets. Harris (2008) collected only one adult during electrofishing surveys of 17 sites within Cowichan, Bear, and Mesachie lakes in the summer of 2008. Using traps, Beamish (1982) and Beamish and Wade (2008) report a total of 265 adults collected from the mouths of Halfway Creek and Robertson River in 1980 and 1981. A similar trap setup collected only four adults from near Halfway Creek in 2008 (Beamish and Wade 2008). Harris (2008) was unable to collect mature adults in tributaries using kick/drift nets, suggesting that spawning rarely occurs in tributaries. However, four mature adults were collected from shorelines and one from Mesachie Creek using Fyke nets. No lamprey were observed during snorkel surveys at the mouths of Halfway, Meades, and Mesachie creeks in 2008 (Harris 2008). Yet, nest building and multiple adults have been observed in tributaries upstream of the lake (Wilson pers. comm.).

Vancouver Lamprey have also been captured incidentally during studies of salmonids; traps for Coho Salmon in Mesachie Creek captured 342 lamprey during 1988 to 1996 (Beamish and Wade 2008). However, only 59 were identified as post-metamorphic and 29 as ammocoetes; life stage is unknown for the rest, although it is likely that many were post-metamorphic (Beamish and Wade 2008). Six adult lamprey were captured during pelagic trawls for Kokanee (*Oncorhynchus nerka*) in July 2010 (Johner and Sebastian 2011). Indirect evidence of lamprey presence is also provided by lamprey scars on fish.

Vancouver Lamprey have not been observed in Cowichan River below the outlet of Cowichan Lake (Beamish 1982); however, the effort involved in verifying their absence generally has not been documented or quantified. Lampreys are frequently caught during electrofishing surveys in Cowichan River, but are not identified to species (McCulloch pers. comm. 2016). All recently metamorphosed lampreys captured by Beamish and Wade (2008) in Cowichan River in 1985 to 1988 were morphologically identified as Western Brook Lamprey or Pacific Lamprey, suggesting that Vancouver Lamprey do not occur in Cowichan River.

HABITAT

Habitat Requirements

Cowichan, Bear, and Mesachie lakes are oligotrophic, a nutrient status typical of coastal lakes in British Columbia (Vancouver Lamprey Recovery Team 2007). The Cowichan Valley experiences a variable climate that is generally warm and dry in summer and mild and wet in winter (Vancouver Lamprey Recovery Team 2007), and these three lakes have temperatures that do not fall below 4ºC. In 2005-2013, maximum surface temperature in the North Arm of Cowichan Lake ranged from 13.7°C to 24.0°C, and minimum surface temperature ranged from 6.5°C to 15.0°C (BC Lake Stewardship Society 2014). The British Columbia Conservation Foundation (2012) surveyed shorelines in Cowichan Lake. They found that shorelines were predominantly gravel (71.9%) or rocky (16.9%), with other habitat types present in smaller amounts (5.6% cliff/bluff, 4.6% stream mouth, 0.5% wetland, 0.5% sandy beach). For Vancouver Lamprey, stream mouth areas are particularly important for both spawning and ammocoete rearing, and gravel shorelines may also be used for spawning (*see* below).

Adult Vancouver Lamprey have been observed spawning on shallow gravel bars in nearshore lake habitat (e.g., at the mouths of several creeks) rather than the riffle areas of streams usually used by other lamprey species (*see* Johnson *et al.* 2015). Mature and maturing adults have been collected at the mouths of Halfway Creek, Meades Creek, and Robertson River (Beamish and Wade 2008; Harris 2008). Harris (2008) observed what appeared to be spawning nests in nearshore lake habitat at the mouth of Meades Creek. However, because ammocoetes have been found in the lower portions of some lake tributaries, some spawning apparently occurs in tributaries as well (Beamish 1987); Harris (2008) captured one adult lamprey in Halfway Creek. It is possible that the use of tributaries for spawning and rearing has been underestimated in previous studies (Wade pers. comm. 2016). Larval occurrence in these creeks could also be due to larval dispersal (Harris 2007). Spawning aggregations have been observed at depths ranging from 20 cm to more than 2 m, and actual spawning was observed at the shallower of these depths. However, it could not be determined if spawning occurred in the deeper waters (Beamish 1987).

After hatching, ammocoetes drift a short distance from the nest, where they burrow into soft fine sediments or sand. Although ammocoetes have been collected within approximately the first 100 m upstream of the mouths of tributaries (Harris 2007; Beamish and Wade 2008), Beamish (1982) found them to be most plentiful along the edge of Cowichan and Mesachie lakes, most often in close proximity to lake tributaries. This again suggests that spawning generally occurs in the lake and the ammocoetes remain in the lake (Beamish 1987). Consistent with this suggestion, ammocoetes have been found in Bear Lake, including at the mouth of the Robertson River, but were not found in the Robertson River itself (Harris 2007) and only two ammocoetes have been found in Mesachie Creek (*see* “Distribution,” above). Similarly, Wade and MacConnachie (2016) found large numbers of small larvae along the shorelines near the mouths of several tributaries, suggesting that spawning occurs in these areas (and that dispersal of larvae may be limited).

Habitat for Vancouver Lamprey ammocoetes appears very similar to that used by lamprey species from riverine habitats (e.g., Beamish and Jebbink 1994; Beamish and Lowartz 1996; Mundahl *et al.* 2006; *see* Dawson *et al.* 2015). Harris (2007) found ammocoetes predominantly where the sediments were composed of medium-fine or fine substrates where there was a layer of organic debris; organic substrates such as decaying leaves or aquatic vegetation were preferable to larger organics that had not yet decomposed. Ammocoetes were rarely captured in areas where small particle substrates (e.g., silts and clays) dominated or in coarse substrates such as gravels and cobble. Beamish and Wade (2008) similarly reported most often finding larvae in habitat with a thin layer (less than 10 cm) of silt covering substrates such as fine sand, gravel, and woody debris. Wade and MacConnachie (2016) found larvae in a variety of habitat types, including sand, silt, and mud, and in some areas with small pebbles. Larvae were present in areas both with and without organic debris. Substrate particle sizes were not quantified in any studies of Vancouver Lamprey larvae, but the preferred particle size range for other lamprey species includes particles from 0.05 to 2 mm diameter (Dawson *et al.* 2015).

As for their depth distribution, however, relatively little is known as ammocoetes have primarily been captured using a backpack electroshocker (which is only possible at depths of about one metre or less). Harris (2007) was limited to electrofishing at depths of no more than 120 cm, but ammocoetes were found up to this maximum depth. Habitat that appeared suitable for ammocoetes was found beyond this depth, but dredging would be required to determine the maximum depth distribution of Vancouver Lamprey ammocoetes (Harris 2007). Using boat electrofishing, Beamish and Wade (2008) captured six ammocoetes and one adult in approximately 2 m of water near the mouth of Halfway Creek. Due to the relatively few lamprey found in deeper water, they speculated that most ammocoetes occur in shallower water. It should be noted that boat electrofishing is less effective for smaller fish (Zalewski 1985; Dolan and Miranda 2003), and specialized equipment is generally needed to detect lamprey larvae in deep water (Bergstedt and Genovese 1994; Mueller *et al.* 2012). Therefore, standard boat electrofishing may not have been ideal for detection of Vancouver Lamprey larvae in deeper water.

Relatively little is known about Vancouver Lamprey during its feeding (juvenile) phase, i.e., between the time of metamorphosis and spawning. Vancouver Lamprey metamorphoses into a juvenile from July to October and likely remains in the substrate until the spring of the following year. In the spring, juveniles begin feeding and attack large numbers of young salmonids (Beamish 1987; *see* “Biology,” below). It is assumed that during this time, Vancouver Lamprey seek prey in a variety of areas, including the water column, but the habitat requirements of this life stage are not known (Vancouver Lamprey Recovery Team 2007).

Habitat Trends

Recent studies have examined Vancouver Lamprey habitat usage and distribution (e.g., Harris 2007, 2008; Beamish and Wade 2008; Wade and MacConnachie 2016). However, there have been few studies that attempt to quantify habitat availability or changes in habitat.

Drought-induced habitat loss is a recent concern (*see* “Threats,” below). Low precipitation in the past few years has reduced tributaries of Cowichan Lake to “trickles”, lowered the level of Cowichan Lake, and resulted in seasonal exposure of the vital stream mouth habitat (MacConnachie pers. comm. 2016; McCulloch pers. comm. 2016). This is reflected in reduced outflow in Cowichan River, where a monitoring station has collected data since 1960. Summer flow rates were near average in 2012 and 2013, but decreased to near the historical minimum in 2014 and 2015 (the most recent years for which data were available; Figure 6).

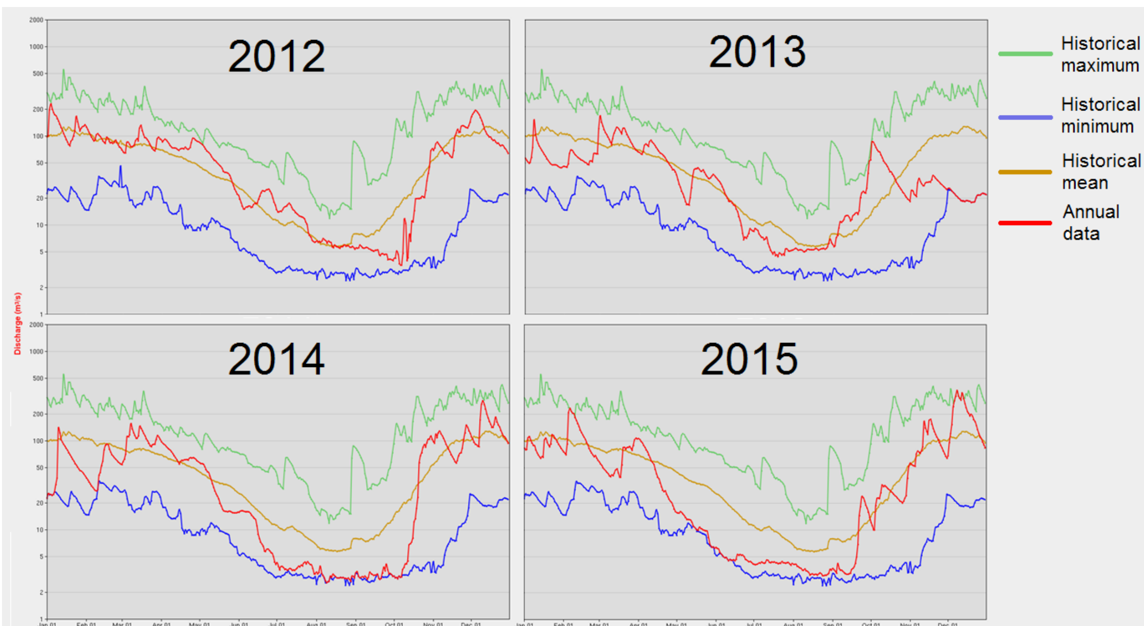

Figure 6. Daily flow rates at water monitoring station 08HA011 (Cowichan River near Duncan). Graphs show the historical maximum (green line), mean (orange line), and minimum (blue line) flow rates, compared to the flow rates in 2012-2015 (red line). Data are from 1960 to 2015 and images are modified from Environment Canada (2017).

The water level of Cowichan Lake is controlled by a weir, which was installed in 1957 and regulates outflow from the lake into Cowichan River; it allows up to one metre of water to be stored. The stored water can then be released periodically to maintain sufficient flows in Cowichan River for salmon migration and human use (BC Lake Stewardship Society 2014; MacConnachie pers. comm. 2016). In recent years, summer water levels have been relatively low compared to the available post-weir historical data (1971-2015; Figure 7). The Cowichan Basin Water Management Plan (Westland Resource Group Inc. 2007) suggested two main actions regarding the weir: a) raise the weir approximately 30 cm to retain more water from spring runoff; and b) install pumps below the “zero storage” level of the weir, to allow pumping of water into Cowichan River even if lake levels fall below the bottom of the outflow structure in the weir. The weir has not yet been raised, but evaluations and planning are ongoing (McCulloch pers. comm. 2016; Hatfield pers. comm. 2017). Pumps were installed in September 2016 and may be used to decrease the lake level up to 30 cm below zero storage (Ptolemy pers. comm. 2017). There is concern that lamprey habitat (particularly the shallow stream mouth areas) may become exposed during the late summer period due to pumping of water over the weir (McCulloch pers. comm. 2016; Ptolemy pers. comm. 2017). If the weir is raised, this would likely increase lamprey spawning habitat by ensuring that stream mouth areas are underwater during the spawning season (MacConnachie pers. comm. 2016), but there would still be the potential for seasonal exposure of ammocoete rearing habitat due to pumping in the late summer and fall.

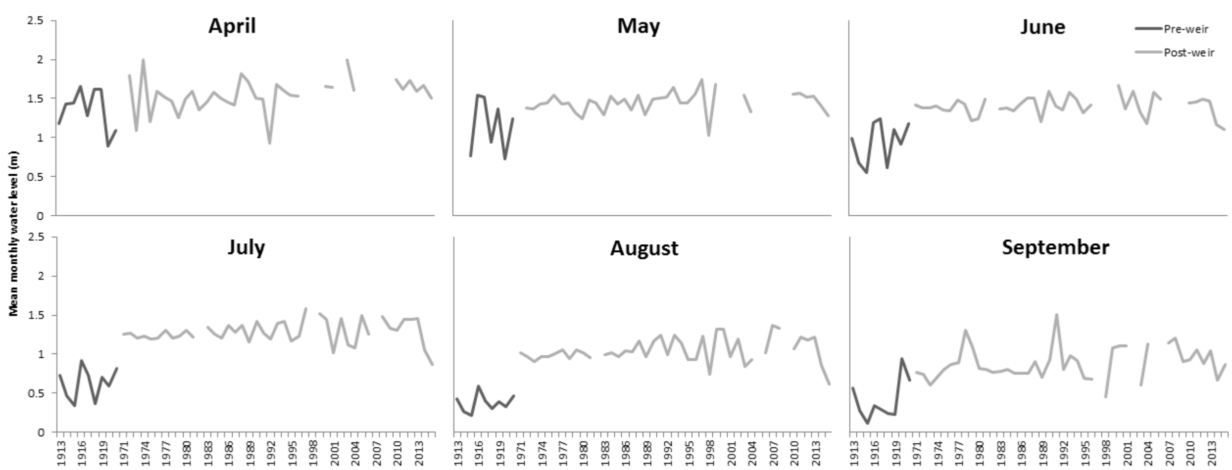

Figure 7. Mean monthly water levels (April to September) at water monitoring station 08HA009 (Cowichan Lake near Lake Cowichan). The Cowichan Lake weir was installed in 1957; graphs show the available historical data for pre-weir (1913-1921) and post-weir (1971-2015) periods. Data from Environment Canada (2016).

Beamish (2001) suggested that increasing siltation of lakes and rivers may be increasing habitat for larval Vancouver Lamprey, but siltation may also cause a loss of shallow water gravel areas for spawning, which would presumably have an adverse effect. It appears that Mesachie Lake, in particular, has been affected by increasing siltation. Mesachie Lake was used as a log storage area for a local mill during the early 20th century and many logs sank during this time. During the 1980s, there was a log salvage operation on the lake that resulted in a redistribution of the bottom sediments throughout the lake; it is possible that some sediments would have settled on the lamprey spawning areas (Baillie pers. comm. 2007). The long-term effects of historical siltation are unknown. There are also concerns that historical and ongoing forestry activities may result in increased sedimentation in tributaries, and this sediment may reduce habitat availability in tributaries and at stream mouths (*see* “Increased sedimentation from forestry,” below). Sediment buildup has been observed at the mouths of Sutton and Robertson creeks (Wilson pers. comm. 2017).

Since the description of Vancouver Lamprey in 1982 (Beamish 1982), new houses have been built near the spawning grounds at Halfway Creek, and a summer camp has been constructed near Mesachie Creek (Beamish and Wade 2008). Residents of Mesachie Lake have created new gravel beaches near Mesachie Creek, which may provide additional spawning habitat (Beamish and Wade 2008); however, the gravel size may not be optimal for lamprey spawning (Harvey 2015), and there may not be sufficient inflow of water to support spawning (*see* Vancouver Lamprey Recovery Strategy 2007, Beamish and Wade 2008). These new residences and beaches may have negative effects on shoreline habitat. The British Columbia Conservation Foundation (2012) compared shoreline disturbance in three developments along the shoreline of Cowichan Lake in 2006 versus 2010. In this time frame, shoreline modification occurred in 5% of properties in Walton Road, 24% of properties in Youbou, and 52% of properties in the Creekside development. Docks and retaining walls were the most common forms of disturbance. R. Ptolemy (pers. comm. 2017) also reported the installation of pilings near the important stream mouth habitat at the mouth of Meades Creek in 2014. Local residents report that regulations regarding shoreline modification are not consistently enforced (Wilson pers. comm. 2017).

BIOLOGY

Until recently, virtually all the known information about the biology of Vancouver Lamprey had come from research published by Beamish (1982), and little research had been done on this species since the mid-1980s. Additional research has recently been conducted by Harris (2007, 2008), Beamish and Wade (2008), Taylor *et al.* (2012), and Wade and MacConnachie (2016), and by the Province of British Columbia, with most studies focusing primarily on lamprey habitat and distribution. These findings are included here. In addition, data from the Mesachie Creek salmon enumeration fence regarding lamprey occurrence records and wounding rates on Coho Salmon smolts (from 1987 to 1996) were provided by S. Baillie (Fisheries and Oceans Canada) and were analyzed in COSEWIC (2008). Vancouver Lamprey Recovery Team identified some of the key information gaps that inhibit conservation of this species (Vancouver Lamprey Recovery Team 2007), and many of these information gaps are identified below.

Life Cycle and Reproduction

The life cycle of the Vancouver Lamprey consists of two distinct life history stages: a blind, filter-feeding larval stage and the juvenile or adult phase. Beamish (2001) estimated that the larval phase lasts approximately 6 years, and the juvenile or adult phase probably 2 years. However, age estimates from length-frequency curves and statolith banding patterns in other lamprey species (e.g., Medland and Beamish 1987) show that length of the larval stage can vary considerably among individuals (*see* Dawson *et al.* 2015), and Beamish (2001) acknowledged that his estimate of life span is an “educated guess.” A more recent study (Beamish and Wade 2008) used length-frequency distributions to estimate the length of the larval period as approximately five years.

Like all lampreys, Vancouver Lamprey is semelparous, that is, they reproduce only once during their lifetime and die following reproduction (although it should be noted that repeat spawning has been suggested in a few marked Pacific Lamprey individuals; Michael 1980, 1984). Estimated generation time (the average age of parents at the time of reproduction) is approximately seven to eight years (Beamish 2001; Beamish and Wade 2008).

In Vancouver Lamprey, reproduction occurs from May to August. Starting the description of the life cycle with the larval phase, hatching would occur approximately 2-3 weeks after fertilization (Piavis 1961; Smith *et al.* 1968). Unlike most other lamprey species where ammocoetes rear in rivers and streams, it appears that Vancouver Lamprey larvae remain in the lake in the vicinity of creeks (Beamish 1982), although ammocoetes have also been collected quite far from tributaries (Harris 2007). Some ammocoetes have been found in the lower portions of some lake tributaries, but few at distances greater than 100 m from the lake (Beamish 1982) and virtually no ammocoetes have been found in Mesachie Creek or Robertson River (Harris 2007; *see* “Distribution,” above). Although the biology of Vancouver Lamprey has not been well studied, it appears that other aspects of the larval phase are similar to other lamprey species. After hatching, lamprey prolarvae burrow into sand, silt and detritus (*see* “Habitat Requirements,” above) where they feed by filtering microscopic plant and animal material and detritus through the oral hood (Dawson *et al.* 2015). Vancouver Lamprey ammocoetes may grow as large as 17 cm, but metamorphosis generally begins at lengths of approximately 12-14 cm (Beamish 1982).

Vancouver Lamprey metamorphoses into a young adult (juvenile) from July to October (Beamish 1982). Metamorphosing lamprey have been collected in Cowichan and Mesachie lakes from mid-September to mid-November, but the stage of metamorphosis was not as advanced as that of Pacific Lamprey collected from the same time period from other areas (Beamish 1982). Following metamorphosis, the juvenile probably overwinters in the substrate and begins feeding in the open waters of Cowichan and Mesachie lakes the following spring (Beamish 2001). Juvenile Vancouver Lamprey readily attack young salmonids, including Coastal Cutthroat Trout (*O. clarkii clarkii*), Dolly Varden (*Salvelinus malma*), and age 1 and 2 Coho Salmon. Locals reported frequently seeing lamprey scars on Coastal Cutthroat Trout in particular (Beamish and Wade 2008; *see* Figure 8); this may be due to anglers targeting Coastal Cutthroat Trout. A snorkel survey of spawning Coastal Cutthroat Trout in 2011 found that lamprey were attached to about 10% of spawners, and a further 80% of spawners had one or more lamprey scars (Lough *et al.* 2011). Up to 90% of Coastal Cutthroat Trout captured by angling have lamprey scars, and most have more than one scar; in about 5% of captured Coastal Cutthroat Trout, lamprey scars are very fresh (indicating recent feeding) or a lamprey is seen detaching from the fish as anglers bring their catch close to the boat (McCulloch pers. comm. 2016). Other species that are present in the lakes and that may be prey for Vancouver Lamprey include Kokanee and steelhead and Rainbow Trout (*O. mykiss*; FISS 2017). Brook Trout (*Salvelinus fontinalis*) were stocked in 1908, and Atlantic Salmon (*Salmo salar*) were stocked several times between 1912 and 1934 (FISS 2017); however, S. Baillie (pers. comm. 2007) has indicated that Atlantic Salmon are not present and Brook Trout have not been seen for several decades. Adults of anadromous species, such as Coho Salmon and steelhead, are only present during the spawning season (British Columbia Conservation Foundation 2013). Chinook Salmon (*O. tshawytscha*) are also listed as occurring in Cowichan Lake (FISS 2017) but are seldom present; they are usually present only in the Cowichan River and only for a maximum of three months post-emergence (Baillie pers. comm. 2007). A 2012 snorkel survey of nearshore fish populations in Cowichan Lake did not locate any Atlantic Salmon, Brook Trout, or Chinook Salmon (British Columbia Conservation Foundation 2013). Lamprey feeding continues throughout the summer and fall and into the winter (Beamish 1987).

It is believed that reproduction by Vancouver Lamprey occurs the following spring/summer, i.e., two years after metamorphosis (Beamish 1987). This species appears to experience a relatively short non-feeding period prior to spawning compared to the Pacific Lamprey (Beamish 1980) and many other migratory lamprey species (reviewed in Moser *et al.* 2015), but similar to that of other freshwater-resident parasitic lampreys (e.g., Bergstedt and Swink 1995; Moser *et al.* 2015). The largest sexually immature Vancouver Lamprey reported was 27.3 cm and the largest mature specimen was 25.6 cm (Beamish 1982), implying only a small amount of shrinkage during maturation. In contrast, Pacific Lamprey from the Skeena River system may enter fresh water up to one year before spawning and, during this time, decrease approximately 20% in length (Beamish 1980).

Figure 8. Coastal Cutthroat Trout *Oncorhynchus clarkii clarkii* with multiple lamprey scars. Photos provided by Joy Wade; used with permission.

Spawning aggregations of male and female Vancouver Lamprey have been observed from May to August in Cowichan and Mesachie lakes. Beamish and Wade (2008) reported higher numbers of spawners in May and June and lower numbers in July and August; spawning nests were observed at the mouths of Halfway Creek and Robertson River in June. Spawning mostly occurs on shallow gravel bars in nearshore lake habitat, although some spawning apparently occurs in tributaries as well (Beamish 1987; Wilson pers. comm.) (*see* "Habitat Requirements," above). Because other lamprey species require clean gravel with interstitial flow or groundwater upwelling for spawning and incubation, it is assumed that Vancouver Lamprey has similar requirements (Vancouver Lamprey Recovery Team 2007).

Other requirements for spawning are not well known. For example, there are no reports of the water temperature at which Vancouver Lamprey spawn. Pacific Lamprey in Washington State spawn at water temperatures ranging from 10.1 to 17.3ºC (from the first week of May to the end of July; Stone 2006). Beamish (1980) observed spawning in Pacific Lamprey in the Stamp and Englishman rivers (Vancouver Island) in April and June, respectively, and Pletcher (1963) reported that April to May was the main spawning period for Pacific Lamprey. In general, spawning in Vancouver Lamprey occurs later than in the Pacific Lamprey, but whether this is because of different lake temperatures or different temperature preferences has not been determined.

NatureServe (2015) described Vancouver Lamprey as a communal spawner. Spawning behaviour has been observed in the laboratory and is reported by Beamish (2001) to be similar to behaviours described by Pletcher (1963) for Pacific and Western Brook lampreys. In the Western Brook Lamprey, a single nest may contain as many as 12 spawning lamprey, and Pacific Lamprey males may mate with more than one female in different nests (Pletcher 1963; *see* Scott and Crossman 1973). There have been no reports of sex ratios in spawning Vancouver Lamprey. The sex ratio of upstream migrating Pacific Lamprey was approximately equal in four of five streams studied by Beamish (1980). However, it is not uncommon to have skewed sex ratios at spawning in other lamprey species, and male-biased sex ratios are frequently reported (e.g., Hardisty 1954, 1961; *see* Johnson *et al.* 2015). Beamish (1987) suggested that population size may influence sex ratio in Vancouver Lamprey. It may be possible to determine sex ratios non-invasively (i.e., without dissection) in Vancouver Lamprey, as males are readily identifiable by the presence of an external genital papilla (Beamish 1982).

There are no known reports on the fecundity of Vancouver Lamprey, but because fecundity is generally correlated with adult size (Vladykov 1951), it should be possible to extrapolate from other parasitic lamprey species. Fecundity in populations of the Silver Lamprey (*Ichthyomyzon unicuspis*), where total length at maturity was approximately the same as that observed in Vancouver Lamprey (i.e., 20-25 cm), averaged 14,310-15,470 eggs per female. No estimates of survival rates are available for Vancouver Lamprey, but lampreys appear to be able to increase in abundance relatively rapidly, indicating a relatively high rate of larval and juvenile survival at low population levels (Beamish 1987). The wide range of survival rates estimated for various stages of the Sea Lamprey under different conditions (Howe *et al.* 2004; Dawson *et al.* 2015) supports this.

Physiology and Adaptability

The most notable aspect of the physiology of Vancouver Lamprey is its ability to osmoregulate in fresh water throughout its entire life cycle (Beamish 1982). In contrast, even though feeding-phase Pacific Lamprey are able to survive in fresh water for up to several months, they are incapable of surviving in fresh water for the duration of the parasitic feeding phase (Beamish 1980, 1982; Clarke and Beamish 1988). Vancouver Lamprey can also live and feed in salt water, although it appears to be not as well adapted to sea water as the Pacific Lamprey. Beamish (1982) found that Vancouver Lamprey died when subjected to increasing concentrations of salt water in the earlier stages of metamorphosis, but were able to survive in full-strength salt water a few months later.

Other than this, little has been reported regarding the physiology of Vancouver Lamprey. For example, nothing has been reported regarding its thermal tolerance and preference. Survival and development of other lamprey species are known to be sensitive to temperature. The optimal temperature for survival of early life stage Sea Lamprey (Piavis 1961; Rodríguez-Muñoz *et al.* 2001) and Western Brook and Pacific lampreys (Meeuwig *et al.* 2005) is 18-19ºC. At higher temperatures (22ºC), survival was significantly reduced (Piavis 1961; Meeuwig *et al.* 2005) and developmental abnormalities increased (Meeuwig *et al.* 2005). At lower temperatures, the response varied among species: no Sea Lamprey embryos survived at temperatures below 15.6ºC (Piavis 1961); whereas Meeuwig *et al.* (2005) found survival in Western Brook and Pacific lampreys at 14 and 10ºC to be similar to that at 18ºC. Once past the embryonic stage, the average lethal temperature for other lamprey species is approximately 28°C (Dawson *et al.* 2015).

Little is known specifically about the adaptability of Vancouver Lamprey (i.e., its tolerance for a variety of environmental conditions). Lampreys in general, however, appear to be quite adaptable (Hardisty 2006). Lampreys have relatively high rates of larval and juvenile survival at low population levels and are likely able to increase in abundance relatively rapidly at such times (Beamish 1987).

It is possible to artificially spawn and rear other species of lampreys in the laboratory (e.g., Piavis 1961). Although attempts to rear large numbers of parasitic lamprey through the entire life cycle have been largely unsuccessful (Swink 2003), it would likely be feasible to artificially spawn Vancouver Lamprey in the laboratory and reintroduce them into Cowichan, Bear, and Mesachie lakes as ammocoetes (*see* Lampman *et al.* 2016). However, because this species is a potentially serious source of salmonid mortality, fisheries managers would not want to transplant this species to any other lake systems (Beamish 2001). Although translocation of adults has been successful in increasing larval population density in Pacific Lamprey (Ward *et al.* 2012), the restricted range of Vancouver Lamprey means that there are no additional populations from which to draw adults for translocation into the Cowichan Lake system. Translocations of Vancouver Lamprey adults within the Cowichan Lake system are theoretically possible, but probably unnecessary, as it appears that adults migrate relatively freely between the lakes (*see* “Dispersal and Migration,” below).

Dispersal and Migration

Available evidence suggests that Vancouver Lamprey has exhibited limited dispersal; that is, it remains within Cowichan, Bear, and Mesachie lakes. No Vancouver Lamprey have been observed below the lake outlets even though there are no physical barriers that prevent access to the sea (Beamish 1982). Vancouver Lamprey is not “landlocked”; therefore, it appears to be non-anadromous and does not undergo long-distance migration (NatureServe 2015).

Indirect evidence, however, suggests that Vancouver Lamprey moves between the three lakes. Although Beamish (2001) reported that no ammocoetes have been found in Mesachie Creek (which connects Bear and Mesachie lakes), juvenile and adult Vancouver Lamprey have been noted in the enumeration fence that was operated on this creek between 1987 and 1996 (Baillie pers. comm. 2007; Beamish and Wade 2008). Lamprey were caught largely in downstream traps (336 total in downstream traps versus 6 total in upstream traps; Beamish and Wade 2008), and the number of lamprey captured in the downstream trap was generally highest in May (Figure 5), which could indicate downstream movement of recently metamorphosed lamprey. Beamish (pers. comm. 2016) reports that upstream movement is more questionable, and lamprey caught in the upstream traps may not have been moving between the two lakes but rather entering the traps for other reasons (e.g., seeking a dark refuge). Genetic differentiation between Cowichan and Mesachie lakes was low to moderate, suggesting at least some ongoing gene flow (Taylor *et al.* 2012; *see* “Population Spatial Structure and Variability,” above). Additional research would be necessary to ascertain the degree and direction of movement among lakes.

Little is known about dispersal within each lake, but observations in this and other lamprey species suggest that Vancouver Lamprey would move freely among suitable habitats within each lake. Although larval dispersal is likely more limited than that of river-rearing species which undergo passive downstream dispersal (e.g., Derosier *et al.* 2007), the juvenile Vancouver Lamprey apparently move to open waters to feed and back to nearshore areas to spawn. Genetic differentiation among sites within each of Cowichan and Mesachie lakes was low to moderate (Taylor *et al.* 2012; *see* “Population Spatial Structure and Variability,” above), supporting the hypothesis that some dispersal occurs.

In other lamprey species, there is no evidence that adults home to their natal spawning sites (Bergstedt and Seelye 1995; Fine *et al.* 2004). In fact, lampreys appear to use the “suitable river strategy”, in which adults detect pheromones released by larvae and use these pheromones to migrate to suitable spawning grounds (Waldman *et al.* 2008). This migration strategy has been most thoroughly studied in the Sea Lamprey (e.g., Bergstedt and Seelye 1995; Fine *et al.* 2004), but is believed to occur in all lampreys (Waldman *et al.* 2008). In Pacific Lamprey, support for the suitable river strategy comes from pheromone studies (Robinson *et al.* 2009; Yun *et al.* 2011) and genetic studies indicating low genetic differentiation among Pacific Lamprey over a wide geographic area (Goodman *et al.* 2008; Spice *et al.* 2012; Hess *et al.* 2013). Migration to spawning grounds has not yet been studied in Vancouver Lamprey; however, it seems reasonable to assume that Vancouver Lamprey adults, like Pacific Lamprey, utilize the suitable river strategy and do not home to their natal sites to spawn.

NatureServe (2015), based on the primary information from Beamish (1987, 2001), considered the Vancouver Lamprey to migrate locally, given this apparent tendency to migrate between lakes and spawning sites.

Interspecific Interactions

Interactions with Pacific Lamprey

It is believed that Vancouver Lamprey does not occur sympatrically with the Pacific Lamprey (Beamish and Wade 2008), but this has not yet been demonstrated conclusively, especially because these two species cannot be definitively distinguished (morphologically or genetically) in the larval stage. Lamprey larvae collected during 2012 habitat surveys were sent to the Pacific Biological Station for genetic analysis (Wade and MacConnachie 2016). This analysis, using 10 microsatellite loci, found that the larvae grouped with previously analyzed Vancouver Lamprey adults and Pacific Lamprey (M. Wetklo, pers. comm. 2016; MacConnachie and Wade 2016). Although this analysis was able to distinguish Vancouver Lamprey from two other lamprey species also present in British Columbia (Western River and Western Brook lampreys), it was unable to determine whether the larvae were Vancouver Lamprey or Pacific Lamprey (M. Wetklo, pers. comm. 2016). Further surveys are required to verify whether all lamprey occurring in Cowichan and Mesachie lakes are indeed Vancouver Lamprey.

However, Beamish and Wade (2008) are confident that Pacific Lamprey are rare or absent in the Cowichan Lake system, based on a lack of reports of spawning adults. It is puzzling that anadromous Pacific Lamprey would not enter Cowichan Lake in search of spawning habitat, as lampreys migrate to spawning habitat following a pheromone released by larvae (Waldman *et al.* 2008; Moser *et al.* 2015). This pheromone does not appear to be species-specific (Fine *et al.* 2004), so Pacific Lamprey would presumably be attracted to the pheromone released by Vancouver Lamprey larvae. As well, there are no physical barriers that would prevent entry of anadromous Pacific Lamprey into Cowichan Lake (Beamish and Wade 2008). Pacific Lamprey are capable of long spawning migrations past obstacles much larger than the Cowichan Lake weir (e.g., through large hydroelectric dams in the Columbia River system; *see* Moser and Close 2002; Keefer *et al.* 2009; Moser *et al.* 2015), and anadromous salmonids pass the weir to access Cowichan Lake. Beamish and Wade (2008) speculate that Pacific Lamprey may not occur in the Cowichan Lake system due to a lack of suitable spawning habitat in the tributaries. Pacific Lamprey, like most lampreys (*see* Dawson *et al.* 2015; Johnson *et al.* 2015), spawn in stream or river riffle areas with gravel or cobble substrate (Pletcher 1963; Stone 2006; Mayfield *et al.* 2014), and the ammocoetes rear in streams and rivers (Torgersen and Close 2004; Stone and Barndt 2005). As most (72%) of the tributaries of Cowichan Lake are intermittent (British Columbia Conservation Foundation 2012), there may be little or no habitat suitable for Pacific Lamprey spawning and rearing. In contrast, Vancouver Lamprey spawn and rear primarily in lake habitat (Beamish 1982; *see* “Habitat,” above). Although there has been documentation of lake spawning by Pacific Lamprey in the Babine Lake system, only about 1% of spawning nests were observed in lake rather than river habitat (Russell *et al.* 1987).

Even if Pacific Lamprey were able to spawn and rear in the Cowichan Lake system, parasitic feeding phase Pacific Lamprey cannot survive entirely in fresh water (Beamish 1982; Clarke and Beamish 1988) and would be expected to migrate to the sea to feed. It is also unlikely that the two species would interbreed, because Vancouver Lamprey reproduces later in the season than the Pacific Lamprey and uses primarily lake habitat rather than river or stream habitat for spawning (Beamish 2001; *see* "Reproduction," above). Furthermore, size differences between the Vancouver and Pacific lampreys would likely further contribute to reproductive isolation (Beamish 1982). Microsatellite evidence also suggests reproductive isolation between Vancouver Lamprey and Pacific Lamprey (Taylor *et al.* 2012; *see* "Name and Classification" and "Population Spatial Structure and Variability," above). Thus, it is likely that interaction between Vancouver Lamprey and Pacific Lamprey is minimal.

<u>Interactions with other species</u>

Larval lamprey feed on suspended organic matter, including detritus, algae, and bacteria (Dawson *et al.* 2015). The productivity of this food base in Cowichan and Mesachie lakes may affect abundance of Vancouver Lamprey (Vancouver Lamprey Recovery Team 2007). However, in river-rearing species at least, food during the larval phase is not thought to be a limiting factor (Moore and Mallatt 1980), and fish biomass data indicate that the productivity of Cowichan Lake tributaries is relatively high (Ptolemy pers. comm. 2017).

During their post-metamorphic feeding phase, Vancouver Lamprey require large numbers of young salmonids, including Coastal Cutthroat Trout, Dolly Varden, and Coho Salmon (Beamish 1982; *see* "Life Cycle and Reproduction," above). Carl (1953) reported that 80% of the fish examined from Cowichan Lake showed signs of having been attacked by lamprey, Lough *et al.* (2011) reported that about 80% of spawning Coastal Cutthroat Trout had lamprey scars and a further 10% had a lamprey attached, and McCulloch (pers. comm. 2016) stated that up to 90% of angled Coastal Cutthroat Trout in Cowichan Lake have lamprey scars. In Mesachie Lake, Beamish (1982, 2001) reported that up to 50% of fish collected throughout the years showed evidence of lamprey attacks. Figure 8 shows Coastal Cutthroat Trout with multiple lamprey scars. Lamprey have also been captured during trawls for Kokanee (Johner and Sebastian 2011), which suggests that Vancouver Lamprey may target Kokanee as a prey source (Wilson pers. comm. 2017).

Previous reports (*see* COSEWIC 2008) suggested that Coho Salmon were the most important prey source for Vancouver Lamprey; however, it now appears that this was inaccurate. More recent reports indicate that Coastal Cutthroat Trout are likely a more important prey source (Harris 2007; Beamish and Wade 2008; MacConnachie and Wade 2016; McCulloch pers. comm. 2016; Wade and MacConnachie 2016). MacConnachie and Wade (2016) suggest that previous reports of scarring on juvenile Coho Salmon may have been due to the historical practice of rescuing Coho Salmon trapped in tributaries by declining water levels and depositing them into Mesachie Lake. It should be noted that the primary recreational fish in Cowichan Lake is Coastal Cutthroat Trout (McCulloch pers. comm. 2016), which probably contributes to more frequent observations of lamprey scars on Coastal Cutthroat Trout. The recreational fishery for Rainbow Trout is smaller, but Ptolemy (pers. comm. 2017) reports that approximately 80% of large Rainbow Trout have lamprey scars, suggesting that Rainbow Trout may also be an important food source. In order to determine whether Vancouver Lamprey are opportunistic parasites or feed preferentially on certain species, further research (e.g., a systematic survey of lamprey scarring within the Cowichan-Mesachie lake system) would be necessary.

Although Coastal Cutthroat Trout are now assumed to be the more important prey species, predation on Coho Salmon has been more thoroughly studied due to the salmon enumeration fence in Mesachie Creek between 1987 and 1996. Up to 34% of the Coho Salmon smolts caught in the downstream trap (from April to June) bore lamprey wounds, although scarring rates were as low as 7.3% in 1992. From 1987 to 1991, 16.5-34.3% of these Coho Salmon smolts had multiple lamprey wounds (2-6 wounds per fish). The mortality rate of fish preyed on by Vancouver Lamprey is unknown, but some mortality of host fish does occur. In 15% of salmonids examined by Beamish (1982), wounds penetrated into the body cavity or deeply into the muscle and likely would have been fatal. In the Coho Salmon smolts examined from the Mesachie Creek enumeration fence in 1988-1990, over 36% had severe, open wounds that exposed flesh or viscera (data from S. Baillie, pers. comm. 2007). The relatively small size of Coho Salmon smolts may make them particularly vulnerable to severe wounds from lamprey attacks. In the summer of 1980, Beamish (1982) found dead Coho Salmon on the bottom of the lake and washed up along the shore, with wounds suggesting they were killed by lamprey. Adult Coho Salmon are only present in Cowichan Lake from September to December (British Columbia Conservation Foundation 2013); therefore, these fish must have also been smolts.

Nothing has been reported specifically about predation on juvenile Vancouver Lamprey, but salmonids and other fishes are known to prey on the eggs of other lamprey species at spawning time (Dawson *et al.* 2015). Predation on the ammocoetes is thought to be minimal because they are buried in the substrate, and it appears that some fish species have an aversion to the taste of large ammocoetes, perhaps as the result of skin secretions (Pfeiffer and Pletcher 1964; *see* Scott and Crossman 1973). Nevertheless, because ammocoetes are used successfully as bait (Close *et al.* 2002), it is assumed that some fish will feed on ammocoetes if given the opportunity. In river habitats, ammocoetes may be vulnerable to predation during scouring events that dislodge them from their burrows (Close *et al.* 2002; Maitland *et al.* 2015), but the extent to which this might be important in Cowichan and Mesachie lakes is unknown.

Likewise, nothing has been reported about predation on juvenile and adult Vancouver Lamprey. However, other lamprey species (e.g., downstream migrating Pacific Lamprey) are found in the diets of piscivorous fish (Close *et al.* 2002; Cochran 2009) and adult lampreys spawning in shallow water may be vulnerable to predation by birds [e.g., predation on Northern Brook Lamprey (*Ichthyomyzon fossor*) by Common Raven, *Corvus corax* (Scott and Crossman 1973), or Silver Lamprey by gulls (Cochran *et al.* 1992)], or other animals [e.g., predation on spawning adult Pacific Lamprey by Mink, *Neovison vison* (Beamish 1980)].

POPULATION SIZES AND TRENDS

Sampling Effort and Methods

The search effort used to collect Vancouver Lamprey has not been sufficiently quantitative to measure population sizes or make confident assessments of population trends (*see* "Search Effort," above). Searches for ammocoetes and recently metamorphosed lamprey were conducted using electroshockers along the edges of Cowichan, Bear, and Mesachie lakes and in outlet and inlet streams (e.g., Beamish 1982; Harris 2007; Beamish and Wade 2008; Wade and MacConnachie 2016). However, these studies focused on distribution and habitat preference rather than abundance. Feeding phase and mature lamprey have been sampled using seines, nets, and traps, and were also obtained from sports caught fishes (Beamish 1982; Beamish and Wade 2008; Harris 2008; Wade and MacConnachie 2016), but sampling efforts were generally not adequately quantified. Feeding phase lamprey were also captured incidentally during trawls for Kokanee (Johner and Sebastian 2011).

Changes in Vancouver Lamprey abundance have been inferred from changes in the scarring rates of salmonids, as determined from comments from fishers about the incidence of observed lamprey wounds (Beamish 2001), but these fluctuations likewise have not been sufficiently quantified. As well, the scarring rate may be influenced by fluctuations in salmonid populations. Although scarring data are available for Coho Salmon smolts at an enumeration fence on Mesachie Creek between 1987 and 1996, it is difficult to draw firm conclusions about lamprey abundance from these or other scarring data.

For this report, the microsatellite dataset produced by Taylor *et al.* (2012) (*see* "Intraspecific population structure," above) was reanalyzed in an attempt to estimate Vancouver Lamprey abundance in the entire Cowichan Lake system. Taylor *et al.* (2012) collected Vancouver Lamprey larvae (of several age classes) from five sites in Cowichan Lake and two sites in Mesachie Lake in 2007-2008 and genotyped them using eight microsatellite loci. Effective population size (N_e) was estimated using two methods: the sibship method as implemented in Colony v. 2.0.6.1 (Jones and Wang 2010) and the linkage disequilibrium method as implemented in NeEstimator v. 2.0.1 (Do *et al.* 2014). Because Vancouver Lamprey are thought to migrate relatively freely within each lake, and some migration likely occurs between lakes (*see* "Dispersal and Migration," above), N_e was calculated for each lake separately and for the two lakes together; which approach is most appropriate will depend on the degree of migration between lakes (which is not fully understood). Analysis in Colony was performed with a medium run length and both male and female polygamy permitted; all other settings were defaults. Analysis in NeEstimator was performed with a random mating model, and alleles with frequency lower than 0.05 were excluded.

Effective population size is based on an idealized population and is generally smaller than the actual population size N (Palstra and Ruzzante 2008). Ratios of N_e/N are quite variable (Palstra and Ruzzante 2008; Palstra and Fraser 2012; Bernos and Fraser 2016), but an N_e/N range of 0.05 to 0.20 would probably be reasonable for Vancouver Lamprey (Fraser pers. comm. 2017) and was used to estimate Vancouver Lamprey abundance. Furthermore, because multiple age classes of larvae were sampled, the estimate of N must be divided by the generation time of Vancouver Lamprey (seven to eight years; *see* “Life Cycle and Reproduction,” above) in order to estimate the number of adults per year (Fraser pers. comm. 2017). In order to be conservative, these calculations were performed assuming a generation time of eight years.

The Taylor *et al.* (2012) dataset was also reanalyzed to look for recent (i.e., within the last $2N_e$ to $4N_e$ generations; Piry *et al.* 1999) population bottlenecks that would indicate a decline in numbers. The microsatellite genotypes of individuals from Cowichan Lake, Mesachie Lake, and the two lakes together were analyzed in the program Bottleneck v. 1.2.02 (Piry *et al.* 1999). A one-sided Wilcoxon signed rank test was conducted to test for heterozygote excess (which would indicate a recent bottleneck) using the stepwise mutation model and 1000 iterations.

Abundance

Beamish (2001) provided an estimate that 1000-2000 adults occur in the three lakes, and NatureServe (2015) used this estimate and placed global abundance at 1000-2500 individuals. Harvey (2015), however, considered that this figure may be an underestimate, based on the wide distribution of ammocoetes found by Harris (2007). Similarly, six adults were captured incidentally during trawls for Kokanee (Johner and Sebastian 2011); although lamprey abundance cannot be estimated from Kokanee trawl data, the capture of six adults during fairly limited trawls suggests that the number of adults in Cowichan Lake may be greater than 1000-2000 (Weir pers. comm. 2017). As well, up to 60 juvenile or adult Vancouver Lamprey were collected per year in the downstream trap of the Mesachie Creek enumeration fence (Figure 5), suggesting relatively large numbers of breeding adults in Mesachie Lake. Likewise, in some years (1990, 1996), 1000-2000 Coho Salmon smolts with lamprey wounds were caught in the downstream trap of the Mesachie Creek enumeration fence; up to 34% of these smolts had multiple wounds. However, because we have no information regarding the number of smolts a single lamprey juvenile could attack or their survival rate to maturity, lamprey abundance cannot be estimated from scarring rates.

Taylor *et al.* (2012) estimated the number of breeding adults at several sites using sibship analysis of larvae, and estimates ranged from approximately 20 to 60 adults per site. Although these numbers seem low, the authors point out that larvae were often collected from quite small areas (under 100 m^2), and actual numbers of breeding adults may be higher. For comparison, the same calculations were performed for anadromous Pacific Lamprey from two sites in the Cowichan River, and the estimates for these two sites were 30 and 51 (Taylor *et al.* 2012). Spice *et al.* (2012) estimated the number of Pacific Lamprey adults at 20 sites along the west coast of North America, using similar methodology, and estimates ranged from 19 to 38.

Abundance estimates from the microsatellite dataset produced by Taylor *et al.* (2012) are given in Table 3. Confidence intervals produced by the sibship and linkage disequilibrium methods differed somewhat but generally overlapped. Estimates for Mesachie Lake were 14 to 148 adults for the sibship method and 19 to 2313 adults for the linkage disequilibrium method. Estimates for Cowichan Lake were 51 to 358 adults for the sibship method and 61 to > 658 adults (the upper limit of the 95% confidence interval was infinite) for the linkage disequilibrium method. The greatest correspondence between the two methods occurred when the two lakes were considered together; these estimates were 174 to 1035 adults for the sibship method and 64 to 1668 adults for the linkage disequilibrium method.

Table 3. Estimates of Vancouver Lamprey abundance calculated from the Taylor *et al.* (2012) microsatellite dataset using the sibship and linkage disequilibrium methods. N_e = effective population size; CI = confidence interval. The N_e/N ratio (effective population size/number of adults) was assumed to be 0.05 to 0.20; generation time was assumed to be eight years. Minimum abundance was calculated as N_e/(0.20*8); maximum abundance was calculated as N_e/(0.05*8). *See* "Population Sizes and Trends," above, for further details on calculations.

		N_e (95% CI)		
Method		**Mesachie Lake**	**Cowichan Lake**	**Combined lakes**
Sibship	N_e	35 (22-59)	110 (81-143)	342 (278-414)
	Minimum abundance	22 (14-37)	69 (51-89)	215 (174-259)
	Maximum abundance	88 (55-148)	275 (203-358)	855 (695-1035)
Linkage disequilibrium	N_e	72 (30-925)	263 (98-∞)	200 (102-667)
	Minimum abundance	45 (19-578)	164 (61-∞)	125 (64-417)
	Maximum abundance	180 (75-2313)	658 (245-∞)	500 (255-1668)

Based on the abundance estimates calculated using both methods, the genetic estimate of Vancouver Lamprey abundance would be 65 to >2971 adults. It should be noted that this estimate would apply to 2007-2008, when the samples were collected. The genetic estimate is very rough and is strongly affected by estimates of N_e/N and generation time. The accuracy of future estimates could be improved by sampling more sites and more individuals (Palstra and Ruzzante 2008). A more suitable ratio of N_e/N might be chosen through expert consideration of Vancouver Lamprey life history (Palstra and Ruzzante 2008; Bernos and Fraser 2016), particularly if knowledge gaps are filled in through future research.

The above methods have provided several crude estimates of lamprey abundance, and ecological estimates of Vancouver Lamprey abundance (roughly 1000-2500 and perhaps more) are within the range given by the genetic data. Ecological data (e.g., numbers of lamprey caught in the Mesachie Creek enumeration fence, high rates of scarring on salmonids) suggest that the number of Vancouver Lamprey adults is probably higher than the lowest genetic estimates. Considerably more data (e.g., mark-recapture studies; *see* Bergstedt *et al.* 2003; Young *et al.* 2003) will be required before reliable estimates of Vancouver Lamprey abundance are available. Most mark-recapture studies in other lamprey species have used spawning or pre-spawning adults (Mullett *et al.* 2003; Jang and Lucas 2005; Masters *et al.* 2006). The low numbers of Vancouver Lamprey adults recently captured in traps (Beamish and Wade 2008; Harris 2008) suggests that it might be difficult to capture enough Vancouver Lamprey adults for a mark-recapture study. However, Bergstedt *et al.* (2003) tagged recently metamorphosed Sea Lamprey and recaptured them prior to spawning. This approach might be more suitable for Vancouver Lamprey, as metamorphosing or recently metamorphosed lamprey can be collected in larger numbers via electrofishing. As well, Silver *et al.* (2009) suggest that visible implant elastomer tags may be a viable option for estimating larval population abundance using mark-recapture techniques.

Fluctuations and Trends

In general, any inferences about Vancouver Lamprey population trends will be crude, as high-quality quantitative studies have not yet been performed. NatureServe (2015) stated that the short-term trend of the population is unknown (but fluctuations seem to occur), and the long-term trend is somewhere between a decrease of less than 30% and an increase of 25%; however, this is a very rough estimate, and fluctuations would be expected to occur in any population.

Using the Taylor *et al.* (2012) dataset, no evidence for population bottlenecks was found in Cowichan Lake ($P = 0.15$), Mesachie Lake ($P = 0.29$), or both lakes combined ($P = 0.23$). This suggests that, as of 2007-2008 when the samples were collected, there had been no recent declines in abundance. However, it should be noted that this technique may not detect anything but substantial changes (Piry *et al.* 1999).

Observed changes in salmonid scarring rates from fishers (*see* “Search effort,” above) suggest short-term fluctuations in Vancouver Lamprey abundance (Beamish 2001). Similarly, the number of Coho Salmon smolts recorded with lamprey wounds at the Mesachie Creek enumeration fence ranged from 139 (in 1989) to 1982 (in 1996) (Table 1); no decline or increase was evident ($r^2 = 0.10$). Comparable pre-1987 or post-1996 values are not available, and the most suitable conclusion from these scarring data is that lamprey abundance probably fluctuates over time (but the magnitude of these fluctuations is unknown). As salmonid populations also fluctuate, scarring rates cannot be used as accurate indicators of total lamprey abundance. Between 1987 and 1996, the number of juvenile or adult lamprey caught in the downstream trap at the Mesachie Creek enumeration fence ranged from four (in 1991) to 60 (in 1995); again, no decline or increase was evident ($r^2 = 0.33$). As well, Mesachie Lake is much smaller than Cowichan Lake (*see* "Extent of Occurrence and Area of Occupancy," above) and presumably contains a much smaller proportion of the lamprey population (*see* "Abundance," above).

In two instances, rough comparisons may be made between collections of Vancouver Lamprey in the early 1980s and in 2008. Beamish and Wade (2008) set similarly constructed traps at the same location near the mouth of Halfway Creek in 1981 and 2008, and they captured 21 adults in 1981 versus 4 in 2008. However, the length of time the traps were in place was shorter in 2008 (May 2 to July 1; 60 days) versus 1981 (April 8 to July 25; 108 days); this probably contributes to the smaller number of lamprey collected in 2008. Beamish (1982) collected 94 adults in 1980, compared to only six collected by Harris (2008) in 2008; however, neither study thoroughly quantified their sampling efforts. These studies have resulted in speculation that there may be a decline in the population (Beamish and Wade 2008; Harris 2008); however, differences in sampling methodology make direct comparisons between studies difficult if not impossible.

Without a more accurate method of measuring lamprey abundance (e.g., mark-recapture studies), it is difficult to draw firm conclusions about population trends. As an alternative method of examining population trends, MacConnachie and Wade (2016) suggest electroshocking the same areas for ammocoetes every two to three years and comparing counts over time.

Rescue Effect

Vancouver Lamprey is not known to occur outside of Cowichan, Bear, and Mesachie lakes and there is, therefore, no possibility of rescue from other lakes (*see* "Canadian Range," and "Designatable Units," above).

Although Vancouver Lamprey is derived from Pacific Lamprey, a rescue effect from Pacific Lamprey is unlikely. Clarke and Beamish (1988) demonstrated that post-metamorphic Pacific Lamprey generally have poor ability to survive and feed in fresh water, and they suggested that Pacific Lamprey do not easily form freshwater populations. This is further evidenced by the documented extirpation of Pacific Lamprey upstream of an impassable dam (Beamish and Northcote 1989) and the generally small population size and restricted range of the existing freshwater derivatives of Pacific Lamprey. Even if Pacific Lamprey did form a new freshwater population in the Cowichan Lake system, it is unlikely that this population would have the same unique morphological and life history characteristics as Vancouver Lamprey (e.g., large oral disc, lake spawning). Similarly, other freshwater derivatives of Pacific Lamprey are thought to have evolved separately from Vancouver Lamprey, and at least some of these populations are morphologically and/or genetically distinct from Vancouver Lamprey (*see* "Relationships with other derivatives of Pacific Lamprey" and "Designatable Units," above). These populations are therefore unsuitable for potential rescue of Vancouver Lamprey.

THREATS AND LIMITING FACTORS

Threats

A threats calculator was completed for Vancouver Lamprey, and the overall threat impact level was assigned as Medium. This overall threats assessment was chosen rather than the raw calculator assessment of High-Medium because the impacts of water management decisions and climate change are likely outside the 3-generation window for assessment. The most likely threats to Vancouver Lamprey are discussed below.

<u>Droughts (threat 11.2, impact level Medium-Low)</u>

In recent years, there has been reduced precipitation in the Cowichan Valley (MacConnachie pers. comm. 2016); this has resulted in low water levels in Cowichan Lake (Figure 7; *see* "Habitat Trends," above).

Due to these low water levels, the typical stream mouth spawning and rearing habitat has often been dry and therefore unusable during May to August; this may pose a serious threat to Vancouver Lamprey (MacConnachie pers. comm. 2016). Tributaries have also had reduced or absent flow in late summer (MacConnachie pers. comm. 2016); although it is thought that minimal spawning and rearing occurs in the tributaries (Beamish 1987), this seasonal exposure still results in the loss of some potential habitat (and the loss of fresh water inflow for any remaining stream mouth habitat). If spawning and rearing in the tributaries is greater than previously thought (which is possible in this understudied species; Wade pers. comm. 2016), the loss of tributary habitat could have a larger effect. Quantification of habitat loss due to drought is necessary for full understanding of this threat. A major knowledge gap related to the threat posed by low water levels is the ability of Vancouver Lamprey to relocate spawning and rearing during periods of low water. There have been no studies of Vancouver Lamprey ammocoete movement, and studies in other lamprey species have focused on downstream movement in riverine species without specifically examining responses to seasonal exposure (reviewed in Dawson *et al.* 2015). Even if Vancouver Lamprey are able to relocate spawning and rearing grounds, seasonal exposure of present rearing grounds may result in mortality of ammocoetes. Rapid dewatering of larval lamprey habitat has been observed to cause significant stranding and mortality of Pacific Lamprey larvae in the Klamath River basin in northern California (*see* Maitland *et al.* 2015). The rate at which the water levels drop could pose a threat if larvae cannot relocate fast enough and are stranded (Maitland *et al.* 2015). It is also questionable whether suitable spawning and rearing habitat is present in deeper water, as the bottom of Cowichan Lake drops off sharply near the shoreline (British Columbia Conservation Foundation 2013; MacConnachie pers. comm. 2016). Because Vancouver Lamprey only spawn once before dying, loss of spawning habitat could have a negative effect on the population in only a few years (MacConnachie pers. comm. 2016); as well, loss of rearing habitat may affect multiple year-classes of ammocoetes.

Historical data (*see* Figure 7) indicate that, prior to the installation of the Cowichan Lake weir in 1957, summer water levels were often similar to or lower than in the past few years. This suggests that Vancouver Lamprey may have survived similar dry periods in the past; however, the interaction of droughts and water management may result in a greater threat at present and in the future (*see* “Dams and Water Management,” below). As well, the frequency of droughts and low water levels in the Cowichan Valley is expected to increase due to climate change (Westland Resource Group Inc. 2007).

<u>Dams and water management (threat 7.2, impact level Medium-Low)</u>

A weir was installed at the outflow of Cowichan Lake in 1957, allowing up to one metre of water to be stored and later released to meet water needs in the Cowichan River (BC Lake Stewardship Society 2014). In recent years, reduced precipitation and low water levels in Cowichan Lake have resulted in reduced flows in Cowichan River (Figure 6), and the amount of water stored by the weir is no longer sufficient to meet consumptive and ecological water needs in Cowichan River during the late summer period. Pumps were therefore installed in September 2016 to allow pumping of water over the weir, potentially decreasing water levels up to 30 centimetres below the “zero storage” level (Ptolemy pers. comm. 2017). This will lower the lake level beyond pre-weir conditions, posing a threat to Vancouver Lamprey by exposing areas that have not been exposed for decades, if ever (McCulloch pers. comm. 2016; Ptolemy pers. comm. 2017). The threat of low water levels may be somewhat mitigated if the Cowichan Lake weir is raised 30 centimetres as has been suggested (Westland Resource Group Inc. 2007); however, there is as yet no confirmation that the weir will be raised.

Consumptive water licences on Mesachie Lake amount to approximately 1.4 cm of lake depth, so that the two water licences on this lake were considered to be unlikely to cause substantial harm to this species (Vancouver Lamprey Recovery Team 2007). The Vancouver Lamprey Recovery Team (2007) considered it unlikely that threats posed by unlicensed water users exceed those posed by licensed users. However, Harvey (2015) expressed concern that increased residential water use may pose a threat in Mesachie Lake. Water usage in Bear Lake was not specifically considered by any previous reports, but Bear Lake would be grouped with Cowichan Lake due to the channel connecting the two. As well, water usage in tributaries may have a detrimental effect on stream-mouth spawning and rearing habitat; however, there do not appear to be any data available regarding tributary water usage.

<u>Increased sedimentation due to forestry (threat 9.3, impact level Low)</u>

The Cowichan Lake watershed was historically subject to heavy logging activity, and forestry activities in this region are ongoing (Harvey 2015). The single largest use of Cowichan Lake shoreline (measured by kilometres of shoreline occupied) is forestry, accounting for 48% of shoreline length (British Columbia Conservation Foundation 2012). There are buffer zones between forestry sites and the shoreline, and 85% of forestry-adjacent shoreline is considered to be in a relatively natural state (British Columbia Conservation Foundation 2012). Although Vancouver Lamprey has persisted through periods of more intensive forestry activity than at present, there are concerns that ongoing or historical forestry activities along tributaries of Cowichan Lake may have a detrimental effect on Vancouver Lamprey habitat.

Logging causes increased streambank erosion, resulting in accumulation of sediments downstream. This downstream movement of sediments can take decades, meaning that forestry activities can affect stream morphology and fish habitat long after harvest has stopped (Tschaplinski and Pike 2016). In Cowichan Lake, sediment from forestry accumulates at the mouths of Sutton and Robertson creeks and must periodically be removed to allow passage of other fish species (Wilson pers. comm. 2017). Siltation in tributaries could reduce the outflow required for successful stream mouth spawning and negatively affect any Vancouver Lamprey that spawn or rear in tributaries rather than lake habitat (Wade pers. comm. 2016).

<u>Bycatch of Vancouver Lamprey adults (threat 5.4, impact level Low)</u>

Anglers are known to kill lamprey that are caught attached to fish. Anecdotal reports from an annual fishing derby on Cowichan Lake indicate declining fish catches over time (Beamish and Wade 2008); however, this may be due to angler perception, particularly after the introduction of a regulation requiring that all Coastal Cutthroat Trout larger than 50 cm be released (McCulloch pers. comm. 2016). Real or perceived decreases in fish stocks may increase the animosity of anglers towards lamprey. According to Harvey (2015), the likelihood of mortality to lampreys that are captured as bycatch is high; however, the severity of this threat is difficult to quantify, because the percentage of the adult lamprey population that is captured as bycatch is unknown. The threat may be partially mitigated with better education of anglers (Vancouver Lamprey Recovery Team 2007); this education is now underway (Cowichan Watershed Board 2011; BC Local News 2016; Local News Eye 2016).

<u>Residential development (threat 1.1, impact level Low)</u>

Increased residential development in Cowichan Lake has resulted in increased shoreline disturbance (British Columbia Conservation Foundation 2012; *see* “Habitat Trends,” above), but the effect of shoreline disturbance on the availability of lamprey habitat is unclear.

Limiting Factors

<u>Restricted distribution</u>

The primary limiting factor affecting Vancouver Lamprey is their extremely limited distribution. Although there are no barriers that would prevent downstream migration out of Cowichan Lake and into the sea, and Vancouver Lamprey are capable of surviving in salt water after metamorphosis, it appears that they do not migrate out of the Cowichan Lake system (Beamish 1982). Within the Cowichan Lake system, they are restricted to the areas that provide suitable habitat for each life stage (*see* “Habitat Requirements,” above). The stream mouth habitat type that is particularly important for spawning and ammocoete rearing comprises only 4.6% of the shoreline in Cowichan Lake (British Columbia Conservation Foundation 2012).

Availability of food

Availability of food is likely to be a limiting factor (Harvey 2015). In stream-rearing lamprey species, availability of suspended organic matter for ammocoete feeding is not thought to be a limiting factor (Moore and Mallatt 1980). However, this has not been studied in the lake-rearing Vancouver Lamprey. Johnson *et al.* (2016) showed that tagged Sea Lamprey larvae stocked in the Great Lakes near river mouths (i.e., representing larvae carried from streams into lentic areas) showed substantially slower growth than stream-dwelling Sea Lamprey larvae, but whether the slower growth was the result of limited food availability, and whether lentic areas would consistently show slower growth regardless of species, is unknown.

Adult Vancouver Lamprey may be limited by the availability of salmonids for feeding. Prey availability has been suggested as a limiting factor in at least two other lamprey species (the freshwater-resident Mexican Lamprey (*Tetrapleurodon spadiceus*) and anadromous Pacific Lamprey; Lyons *et al.* 1994, Murauskas *et al.* 2013), but the degree to which prey availability limits Vancouver Lamprey is unknown. There was previous concern that a possible decline in the Coho Salmon population in the Cowichan Lake system had a negative effect on Vancouver Lamprey (Beamish 2001; COSEWIC 2008), but it now appears that Coastal Cutthroat Trout are likely a more important prey source (*see* "Interactions with other species," above) so that declines in the Coho Salmon population may not have a strong effect on Vancouver Lamprey. As well, Coho Salmon abundance has been high in other watersheds on southern Vancouver Island in recent years (Ptolemy pers. comm. 2017). The Coastal Cutthroat Trout population in Cowichan Lake appears to be stable at this time (McCulloch pers. comm. 2016), but long-term data (e.g., catch per unit effort) are lacking. Anecdotal evidence suggests that there may have been a decline in the population (Beamish and Wade 2008), but this may be due to angler perception (McCulloch pers. comm. 2016; *see* "Bycatch of Vancouver Lamprey adults," above). As well, local anglers report dramatic decreases in catches of Rainbow Trout over time (Ptolemy pers. comm. 2017). However, Kokanee are present in high abundance (approximately 8.1 million; Johner and Sebastian 2011), and these and other salmonids present in the system (Dolly Varden, steelhead; British Columbia Conservation Foundation 2013) may provide a "buffer" for Vancouver Lamprey in the event of a decline in Coastal Cutthroat Trout and/or Rainbow Trout.

Reduced genetic diversity

One consideration for the future adaptability of Vancouver Lamprey (e.g., if environmental conditions are altered by climate change or other factors) is their reduced genetic diversity compared to anadromous Pacific Lamprey (Taylor *et al.* 2012; *see* "Intraspecific population structure," above). Small populations with reduced genetic diversity may be less able to adapt to changing environmental conditions (Willi *et al.* 2006).

Number of Locations

Threats to Vancouver Lamprey include droughts, dams and water management, increased sedimentation due to forestry, bycatch of adults, and residential development (*see* “Threats,” above). There is uncertainty about whether these threats will act at the level of each lake or affect the entire Cowichan Lake system similarly. Decreased water levels due to drought are likely to affect the entire system at one time, but the effects may be different within each lake (e.g., the degree of seasonal exposure of tributaries and stream mouths may vary among lakes). Pumping water over the weir at the outlet of Cowichan Lake will likely affect both Cowichan and Bear lakes, due to the channel connecting these lakes. However, Mesachie Lake is only seasonally connected to Bear Lake via Mesachie Creek; thus, it may not be affected by water regulation in Cowichan Lake. The effects of residential development and increased sedimentation due to forestry are likely to be more localized, affecting individual stream mouths. Bycatch of adults by anglers occurs throughout the entire system; however, there is some uncertainty about the degree of Vancouver Lamprey movement among lakes (*see* “Designatable Units” and “Intraspecific Population Structure,” above). If Vancouver Lamprey (and their prey) move freely among lakes, this threat may affect the entire Cowichan Lake system similarly; if movement among lakes is limited, each lake may be affected separately. Due to these uncertainties, the number of locations is estimated to be between one (the entire Cowichan Lake system) and three (Cowichan, Bear, and Mesachie lakes).

PROTECTION, STATUS AND RANKS

Legal Protection and Status

Vancouver Lamprey was designated by COSEWIC as Special Concern in 1986. The species was re-examined by COSEWIC in November 2000 and designated Threatened, and this designation was sustained in the November 2008 assessment. It is listed as a Threatened species under Schedule 1 of the federal *Species at Risk Act* (SARA), making it illegal to kill, harm, harass, capture, or take Vancouver Lamprey. It is also illegal to possess, collect, buy, sell, or trade Vancouver Lamprey, or to damage or destroy their residences. Under SARA, a residence is defined 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” (*Species at Risk Act* 2002). Harvey (2015) suggests that spawning nests and ammocoete burrows may both be considered as residences, whereas MacConnachie and Wade (2016) only consider nests as residences.

Vancouver Lamprey is a red-listed (i.e., extirpated, endangered, or threatened) species in British Columbia (BC Conservation Data Centre 2016); however, this status does not provide any special protections.

Proposed critical habitat for Vancouver Lamprey includes all of Cowichan, Bear, and Mesachie lakes, the waterways connecting them, the first 100 m of all tributaries, and 10–30 m of riparian area along the shorelines of each lake and tributary (MacConnachie and Wade 2016). The entire lake system was included because of the varied habitat requirements of Vancouver Lamprey throughout its life cycle (e.g., spawning and rearing occurs primarily in stream-mouth habitat, but adults use the entire water column) and because of the endemism of this species. Riparian areas are thought to be important for maintaining shoreline integrity and supplying detritus and leaf litter for ammocoetes (MacConnachie and Wade 2016); however, the exact effects of riparian areas on Vancouver Lamprey are still unknown, and MacConnachie and Wade (2016) recommend further study of this issue. The recommendations regarding critical habitat will not be legally binding until they are included in an action plan or recovery strategy for Vancouver Lamprey (MacConnachie and Wade 2016). An updated action plan is due in 2017 (Nantel pers. comm. 2016) and will include identification of critical habitat (Fisheries and Oceans Canada 2016).

The recovery strategy for Vancouver Lamprey states that “The recovery goal for Vancouver Lamprey is to ensure its long-term viability within its natural range. It is likely that this species will always remain at some risk due to its extremely limited distribution” (Vancouver Lamprey Recovery Team 2007). A report on the progress of the recovery strategy implementation was recently released (Fisheries and Oceans Canada 2016). Some areas of progress since the 2007 recovery strategy was written include improved descriptions of habitat availability and usage (e.g., Harris 2007, 2008; Beamish and Wade 2008; Wade and MacConnachie 2016), identification of potential critical habitat (Beamish and Wade 2008; MacConnachie and Wade 2016), and shoreline habitat assessments in Cowichan Lake (British Columbia Conservation Foundation 2012).

Non-Legal Status and Ranks

NatureServe (2015) ranks Vancouver Lamprey as G1G2 and N1N2, and its provincial status is S1S2 (BC Conservation Data Centre 2016). These statuses indicate that Vancouver Lamprey is imperilled to critically imperilled on global, national, and provincial scales, respectively.

Habitat Protection and Ownership

There are no specific habitat provisions for Vancouver Lamprey. Provincial legislation in BC (e.g., the *Water Sustainability Act* and *Riparian Areas Protection Act*) will offer some limited habitat protection and BC Sportfishing Regulations prohibit fishing for and retaining Vancouver Lamprey.

At the federal level, the new *Fisheries Act* applies protection only to fishes that are part of a commercial, recreational, or Aboriginal fishery (i.e., CRA fisheries) or to those that support such a fishery (*see* Hutchings and Post 2013). Vancouver Lamprey does not fall into any of these categories but may benefit from habitat protection and enhancement efforts aimed at other fish species (e.g., commercially and/or recreationally important salmonids).

ACKNOWLEDGEMENTS AND AUTHORITIES CONTACTED

The report writers would like to thank Brendan Anderson (British Columbia Ministry of Forests, Lands and Natural Resource Operations), Steve Baillie (Fisheries and Oceans Canada), Richard Beamish (Fisheries and Oceans Canada), Sean MacConnachie (Fisheries and Oceans Canada), Mike McCulloch (British Columbia Ministry of Forests, Lands and Natural Resource Operations), Martin Nantel (Fisheries and Oceans Canada), and Ron Ptolemy (British Columbia Ministry of Environment) for informative discussions and valuable background information on Vancouver Lamprey and its prey sources. Joy Wade (Fundy Aqua Services) provided photos of lamprey scars on Coastal Cutthroat Trout. Mike Wetklo (Fisheries and Oceans Canada) provided information on an unpublished genetic study involving Vancouver Lamprey. Alain Filion (COSEWIC Secretariat) assisted in the preparation of the distribution map and calculations of extent of occurrence and area of occupancy.

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BIOGRAPHICAL SUMMARY OF REPORT WRITER(S)

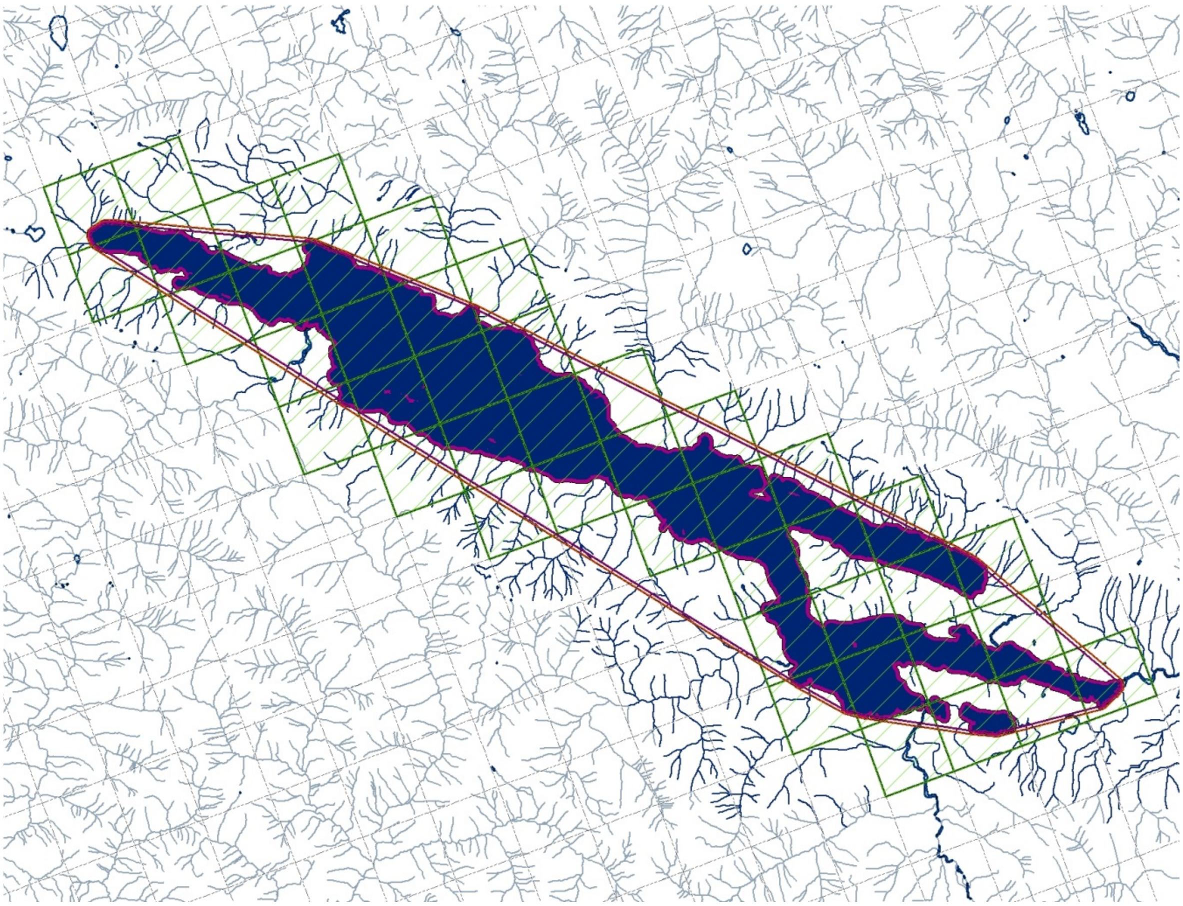
Margaret Docker is an Associate Professor in the Department of Biological Sciences at the University of Manitoba. She has worked on lampreys for over 30 years, and much of her current research deals with the evolution and conservation genetics of lampreys. She is particularly interested in "paired" lamprey species (closely related parasitic and nonparasitic lampreys) and in the environmental, ecological, and genetic factors that contribute to lamprey feeding type.

Erin Spice is a research technician in the Department of Biological Sciences at the University of Manitoba. She has worked on lampreys with Margaret Docker since 2009. Her primary research interests are lamprey paired species and population genetics.

COLLECTIONS EXAMINED

Not applicable.

Appendix 1. Map showing the areas included in calculations of extent of occurrence (EOO) and index of area of occupancy (IAO) for Vancouver Lamprey. The borders of Cowichan and Mesachie lakes are indicated by a thick purple outline along the shoreline. The thin purple line surrounding the lakes indicates the minimum convex polygon used in the calculation of EOO from the boundaries of Cowichan and Mesachie lakes; the thin orange line indicates the minimum convex polygon used in the calculation of EOO with a 100 m buffer zone included around each lake. The 2 x 2 km grid used in the calculation of IAO is indicated by the green squares.



Appendix 2. IUCN Threats calculation on the Vancouver Lamprey.

Species or Ecosystem Scientific Name	Vancouver Lamprey *Entosphenus macrostomus*		
Element ID		**Elcode**	
Date (Ctrl + ";" for today's date):	20/12/2016		
Assessor(s):	Dwayne Lepitzki (moderator and Mollusc SSC co-chair), John Post (SSC co-chair), Erin Spice (writer), Margaret Docker (writer and SSC member), Doug Watkinson, Todd Hatfield (SSC members), Jennifer Shaw, Sean MacConnachie (DFO), Joy Wade, Brendan Anderson (BC MoE) and Angele Cyr (COSEWIC Secretariat).		
References:	draft calculator prepared by Erin and Margaret, & draft COSEWIC status report; telecon 20 Dec.		

Overall Threat Impact Calculation Help:

Threat Impact		Level 1 Threat Impact Counts: high range	low range
A	Very High	0	0
B	High	0	0
C	Medium	2	0
D	Low	3	5
	Calculated Overall Threat Impact:	High	Medium

Assigned Overall Threat Impact:	**C = Medium**
Impact Adjustment Reasons:	Assessed as Medium due to the long time scales climate change thru droughts and water management decsions.
Overall Threat Comments	Generation time 7-8 years therefore 3 gens = 21-24 yrs (for scoring severity and timing); Mesachie (< 1 km2), Bear (between) and Cowichan Lake (62 km2) (upstream to downstream) . Only considering Mesachie Lake and Cowichan Lake. Some lack of knowledge to score by range. Generation time is speculative 7-8 years (could be 5-12) - therefore precautionary = 20-25 years. Post telecon review of the threats assessmment by the SSC and John Post altered the Timing for Water Mangmement and Climate Change to Low (possibly in the long term) given that they are not likley within the 3-generation time window.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1	Residential & commercial development	D	Low	Restricted (11-30%)	Slight (1-10%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1.1	Housing & urban areas	D	Low	Restricted (11-30%)	Slight (1-10%)	High (Continuing)	Scope: In Mesachie Lake, the spawning and rearing grounds near Halfway Creek, which constitute the majority of known spawning and rearing habitat in Mesachie Lake, are affected by new houses. There is also a summer camp and new gravel beds near Mesachie Creek, but this is less important habitat (larvae are rarely found there). In Cowichan Lake, there is development in the southeastern portion of the lake, affecting spawning and rearing habitat near Sutton Creek and Meades Creek. The spawning and rearing habitat along the northwest shoreline does not appear to be strongly affected by development. Overall, we estimate about 11-30% of the population may be threatened by changes to spawning and rearing habitat in developed areas. Severity: The effects of shoreline development on Vancouver Lamprey habitat have not yet been directly studied. We do not know the degree to which larval and spawning habitat are limiting for Vancouver lamprey, but assume that loss of habitat will be have at least a slight negative impact. Timing: Development is ongoing along the shorelines of Cowichan and Mesachie lakes. Structures and nearshore development from new housing development accounted for under this threat. Cowichan is undergoing significant development. docks are being developped nearshore. Generally a recreactional area but increase overtime in and around spawning areas. development is concentrated on one end of Cowichan lake. Other end is remote and not developped and hard to get to. clear cutting in some areas. trailer homes with no septic systems. critical habitat identified at tributaries. some mitigation. dock permitting is self identified so not very active. one spawning area in Mesachie. Cowichan may have alternate spawning area.
1.2	Commercial & industrial areas						not applicable

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
1.3	Tourism & recreation areas						No new development plans. Gravel beach and camp development are past threats. No new plans known of. Expansion of existing commercial docks or new development are not expected other than those accounted for in 1.1.
2	Agriculture & aquaculture						
2.1	Annual & perennial non-timber crops						not applicable
2.2	Wood & pulp plantations						not applicable
2.3	Livestock farming & ranching						not applicable
2.4	Marine & freshwater aquaculture						not applicable
3	Energy production & mining						
3.1	Oil & gas drilling						not applicable
3.2	Mining & quarrying						not applicable. Scope/Severity/Timing: Although there was some illegal gravel mining in some tributaries in recent decades, there has been no recent mining in the Cowichan Lake watershed and these are past threats.
3.3	Renewable energy						not applicable
4	Transportation & service corridors						
4.1	Roads & railroads						not applicable. None known of but active logging roads that have an ongoing effect on habitat quality but no new road widening or development expected.
4.2	Utility & service lines						not applicable
4.3	Shipping lanes						not applicable. some dredging in Shaw Creek (infrequently) but not the lake.
4.4	Flight paths						not applicable
5	Biological resource use	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	
5.1	Hunting & collecting terrestrial animals						not applicable
5.2	Gathering terrestrial plants						not applicable
5.3	Logging & wood harvesting						not applicable. Change in sediment loading accounted for under 9.3

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
5.4	Fishing & harvesting aquatic resources	D	Low	Small (1-10%)	Slight (1-10%)	High (Continuing)	Scope: **Consumptive use of host species** - All or most Vancouver Lamprey adults are affected by the decline in prey abundance (primarily Coho Salmon). **Persecution of Vancouver Lamprey** - All of most Vancouver Lamprey adults are potentially affected by persecution by anglers in Cowichan and Mesachie lakes. Severity: **Consumptive use of host species** - Coho Salmon escapement from Cowichan Lake has decreased approximately 73% since the 1950s. Overfishing may contribute to this decline, although decreased survival of Coho at sea also contributes. In other parasitic lamprey species, lamprey abundance declines with declines in host availability. However, we do not know exactly how much the Vancouver Lamprey population varies with availability of Coho Salmon. Ability to switch to other hosts (e.g., Cutthroat Trout) may provide a buffer. **Persecution of Vancouver Lamprey** - Angler-induced mortality is thought to be high (i.e., of those caught attached to fish), but the total number of lamprey killed by anglers is unknown and likely relatively low or low-moderate. Timing: **Consumptive use of host species** - Although Coho Salmon in Cowichan Lake have not been monitored since 2006, the decline in Coho (relative to their historical abundance) appears to be ongoing. **Persecution of Vancouver Lamprey** - Killing of Vancouver Lamprey adults by anglers is an ongoing threat. Persecution and bycatch accounted for here but host persecution is accounted for 6.3. persecution is not a threat for this species since anglers are not targetting Lampreys. Theyre almost always fishing for other sport fish. So bycatch is accounted for under this threat category. fishing is mostly Cutthroat. almost all Cutthroat parasitized by Lamprey.
6	Human intrusions & disturbance		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
6.1	Recreational activities						some intermittent activity but unlikely affecting spawning area in Mesachie. More likely a threat in Cowichan. Although an activity, unlikley a threat since reacreational activity in sandy beaches occurs when the water level is low which is not when the lamprey is present in nearshore areas. Species seems to be persisting despite ongoing and longstanding threat of recreational activities.
6.2	War, civil unrest & military exercises						not applicable
6.3	Work & other activities		Negligible	Small (1-10%)	Negligible (<1%)	High (Continuing)	Some research but difficult to catch. Lethal sampling is not happening but could be incidental. Province and DFO working on other fish species. Greg Wilson can probably confirm this. Nontargetted sampling resulting in mortality is unlikely to very low. negligible.
7	Natural system modifications	CD	Medium - Low	Pervasive - Large (31-100%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
7.1	Fire & fire suppression						Water withdrawal for fire suppression but unknown to very unlikely that water withdrawal is significantly affecting lake water levels.
7.2	Dams & water management/use	CD	Medium - Low	Pervasive - Large (31-100%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Scope: Water level changes are possible in both lakes due to water usage. Cowichan Lake is likely to be more affected than Mesachie Lake, due to the potential for water level changes related to the weir at the outlet of Mesachie Lake (e.g., pumping water over the weir). Severity: We do not know how lamprey distribution and survival change during low water levels, but historical data indicate that Vancouver Lamprey have survived lower water levels than are common at present. Timing: Water usage and water level changes related to the Cowichan Lake weir are ongoing and expected to continue. Water level is insufficient to sustain spawning habitat. pumping water for consumption occured for the first time this year. climate is driving this via drought (accounted for under 11.2). restriction on raising weir are related to property management which have been mainly resolved.

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
7.3	Other ecosystem modifications		Unknown	Pervasive - Restricted (11-100%)	Unknown	High (Continuing)	Cutthroat main predominant host. Unlikely these lakes have been stocked. Preferred prey species unknown. Too many unknowns to quantify the threat of host abundance since preferred host is unknown (if not generalist to begin with). Decline in Coho but not necessarily Cutthroat in both lakes. unknown impact. could be a negligible impact just like decline in Coho could be beneficial. Is it a limiting factor? threat calculator over all salmonids.
8	Invasive & other problematic species & genes						
8.1	Invasive non-native/alien species/diseases						May be a threat but unknown. Bull Trout increase prey base but interact with existing host.
8.2	Problematic native species/diseases						Potential genetic mixing with Pacific Lamprey but unknown. Likelihood of interbreeding is unlikely and remote.
8.3	Introduced genetic material						not applicable
8.4	Problematic species/diseases of unknown origin						not applicable
8.5	Viral/prion-induced diseases						not applicable
8.6	Diseases of unknown cause						not applicable
9	Pollution	D	Low	Large (31-70%)	Slight (1-10%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
9.1	Domestic & urban waste water						No septic systems for some plots of land subdivided for camping ground (outhouses). Unknown impact. North section of the lake. May be a potential future threat if trend increases.
9.2	Industrial & military effluents						Unlikely

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
9.3	Agricultural & forestry effluents	D	Low	Large (31-70%)	Slight (1-10%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Scope: Approximately 48% of shoreline in Cowichan Lake is used for forestry, but it is uncertain how close these forestry activities and the resulting sedimentation are to lamprey habitat. Lamprey are distributed in stream-mouth habitat around the entire lake; therefore, it is probable that approximately 48% of lamprey habitat/the population is potentially affected by forestry. Severity: There are buffer zones in between forestry areas and the shoreline, which should reduce impact on lamprey habitat. Atlthough forestry has historically increased siltation in these lakes, the increase in siltation due to forestry is likely minimal at present. As well, although increased siltation could reduce spawning habitat, it could increase larval habitat, which could reduce overall negative effects. Timing: Forestry is ongoing in the Cowichan Lake watershed; however, the major impacts of forestry on Vancouver Lamprey (e.g., silation) are primarily in the past. Siltation from logging. severity has impact on tributaries and how they flow down in.
9.4	Garbage & solid waste						not applicable
9.5	Air-borne pollutants						not applicable
9.6	Excess energy						not applicable
10	Geological events						
10.1	Volcanoes						not applicable
10.2	Earthquakes/tsunamis						One in the early 80's with documented significant changes in Coho habitat so this can happen in this area.
10.3	Avalanches/landslides						not applicable
11	Climate change & severe weather	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	
11.1	Habitat shifting & alteration						not applicable

Threat		Impact (calculated)		Scope (next 10 Yrs)	Severity (10 Yrs or 3 Gen.)	Timing	Comments
11.2	Droughts	CD	Medium - Low	Pervasive (71-100%)	Moderate - Slight (1-30%)	Moderate (Possibly in the short term, < 10 yrs/3 gen)	Scope: Climate change is expected to increase the frequency of droughts in the Cowichan watershed. Water level changes are possible in both lakes due to climate change, potentially affecting all Vancouver Lamprey. Severity: We do not know how lamprey distribution and survival change during low water levels, but historical data indicate that Vancouver Lamprey have survived lower water levels than are common at present. The weir at the outlet of Cowichan Lake will help retain water in the lake and buffer the severity of droughts; however, if water is pumped over the weir during droughts, this could reduce the availability of lamprey habitat. Mesachie Lake, which does not have a weir, may be more strongly affected. In the next 3 lamprey generations (approximately 20 years), the effect of droughts on lamprey habitat is likely to be minimal. Timing: Any major effects of climate change on Vancouver Lamprey are likely to occur more than 3 lamprey generations (approximately 20 years) in the future.
11.3	Temperature extremes						not applicable
11.4	Storms & flooding						not applicable. During the winter if at all and mitigated by the dam.
11.5	Other impacts						not applicable