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Recovery Potential Assessment for the Vancouver Lamprey (*Lampetra macrostoma* Beamish)

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

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TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

Vancouver lamprey *Lampetra macrostoma* (Beamish) was designated *Threatened* by COSEWIC in 2000, primarily because it is an endemic species. The species was listed as *Threatened* under *SARA* in 2003. A draft Recovery Strategy has been prepared. The species has been reported only in Lake Cowichan and Mesachie Lake, in south-central Vancouver Island. The lamprey in Cowichan and Mesachie lakes are presently considered to be a single population. Current estimates of 1,000-2,000 adults are not based on systematic sampling, and results of recent sampling studies do not clarify whether the population may have declined in the last fifteen years. Until mark-recapture studies have provided a solid estimate of lamprey abundance, lethal sampling of ammocoetes is allowable harm only in the case of scientific research. Reduction in bycatch mortality is best achieved through awareness. Lamprey depend on angled species for their prey, so those species must not be over-fished

Évaluation du potentiel de rétablissement de la lamproie de Vancouver (*Lampetra macrostoma* - Beamish)

RÉSUMÉ

C'est essentiellement parce qu'il s'agit d'une espèce endémique que le COSEPAC a désigné la lamproie de Vancouver *(Lampetra macrostoma)* (Beamish) comme une espèce *« menacée »* en 2000. L'espèce a été inscrite sur la liste des espèces menacées en vertu de la LEP en 2003. Un programme de rétablissement provisoire a été préparé. L'espèce a été observée uniquement dans les lacs Cowichan et Mesachie, dans le centre-sud de l'île de Vancouver. On considère actuellement que les lamproies présentes dans les lacs Cowichan et Mesachie forment une seule population. Les estimations actuelles de 1 000-2 000 adultes ne sont pas fondées sur un échantillonnage systématique, et les résultats des récentes études d'échantillonnage ne permettent pas de déterminer si la population pourrait avoir diminué ces quinze dernières années. Tant que les études de marquage et de recapture n'auront pas fourni d'estimation solide de l'abondance de la lamproie, l'échantillonnage létal des ammocètes ne constitue un dommage admissible que pour mener des recherches scientifiques. C'est par des campagnes de sensibilisation que l'on parviendra le mieux à réduire la mortalité attribuable à la prise accessoire. Les lamproies se nourrissent d'espèces visées par la pêche à la ligne, qui ne doivent donc pas faire l'objet d'une surpêche.

INTRODUCTION

Vancouver lamprey *Lampetra macrostoma* (Beamish) was designated Threatened by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2000, primarily because it is endemic. The species was listed as Threatened under SARA in 2003. A Recovery Strategy was prepared with the cooperation of DFO and the Province of British Columbia (Vancouver Lamprey Recovery Team 2007).

A Recovery Potential Assessment (RPA) provides technical advice to the Minister of Fisheries and Oceans concerning the amount of allowable harm to an aquatic species. Ideally, an RPA precedes listing of a species or population under SARA, and is used to help make the decision whether or not to list. If the species is already listed, the RPA contains information and technical advice on status, threats, habitat and abundance that can be used to develop recovery plans. Vancouver lamprey belongs to a third category: it is listed under SARA, and a Recovery Strategy has already been written.

The “allowable harm” described in an RPA anticipates Section 73 of SARA, under which the Minister may authorize activities that affect a listed aquatic species, any part of its critical habitat, or the residences of its individuals if all reasonable alternatives that would reduce the impact of the activity have been considered and the best solution adopted so that the activity will not jeopardize the survival or recovery of the species. The RPA helps answer the question: Can the species recover if human-induced mortality is greater than zero? Ideally, the RPA contains information the Minister must place on the SARA Public Registry to document the reasons for issuing a Section 73 permit.

This RPA for Vancouver lamprey was prepared according to revised guidelines that stress a species’ ability to recover from known human activities within the uncertainties posed by limited data (DFO 2007). As a risk assessment, an RPA reflects the data available. In a case like that of the Vancouver lamprey, where there are very limited data on the species’ natural history, abundance and habitat use, an RPA can only provide the best advice with the information available, while noting specific information gaps that need to be filled. The knowledge base on this species is limited to a few peer-reviewed papers and unpublished reports, and first-hand experience remains confined to a small number of experts. There is some very limited scope for drawing inferences from related species (chiefly Pacific lamprey *Lampetra tridentata*); unfortunately, life history and adult size are sufficiently dissimilar to limit the usefulness of such a relative risk assessment. Uncertainties arising from this extremely limited knowledge base are noted throughout the RPA.

The knowledge base on this species is limited and first-hand experience remains confined to a small number of experts. Estimates of larval and adult abundance are needed to fill this critical information gap. It is not currently known what factors limit the abundance of Vancouver lamprey, although one likely determinant is availability of food.

Adult Vancouver lamprey (Figure 1) in Cowichan and Mesachie lakes probably utilize the lake margin and tributary stream areas for reproduction, and the entire water column for feeding. They attack resident fishes, including salmonids. There are major uncertainties concerning preferred spawning areas and their depths, as well as water quality tolerances. Larval lamprey (ammocoetes) are presumed to burrow into fine silt in the littoral zone or in the first hundred metres of inlet streams shortly after hatching, where they filter-feed on algae and organic detritus before emergence. Ammocoetes have a requirement for fine silty substrate associated with decayed organic matter in which to construct burrows.

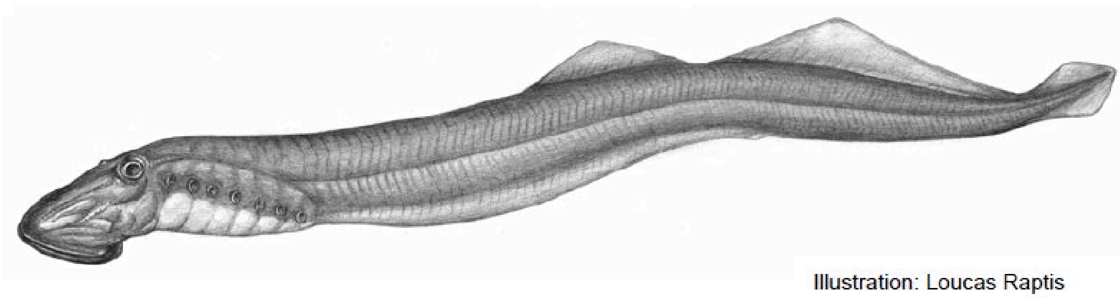

Figure 1. Vancouver Lamprey.

The only known direct mortality on Vancouver lamprey occurs when anglers kill adult lamprey attached to salmonids they have caught. The current threat to the population from logging is low and unquantifiable; it is not expected to increase. Threats to lamprey habitat in Cowichan and Mesachie Lakes are the subject of current research, and a thorough survey of habitat use for the population is required so that harm in the form of habitat alteration can be avoided. Threats from residential development are difficult to quantify because of uncertainty regarding habitat use. Foreshore development could have a serious impact on spawning habitat and the larval stage. There are no known water quality issues in either lake.

An elasticity analysis for Great Lakes lamprey, whose life history resembles Vancouver lamprey, showed that the elasticity of each of the major vital rates was similar. This means that there is no single critical stage that is influential in determining population growth rates. Harm to any life stage will have a similar effect on the population.

I: CURRENT/RECENT SPECIES STATUS

ABUNDANCE, RANGE AND NUMBER OF POPULATIONS

The species has been reported only in Cowichan Lake and Mesachie Lake, in south-central Vancouver Island (Beamish 1982) (Figure 2); larvae have also been found in Bear Lake, a small body connecting Cowichan and Mesachie lakes (Harris 2007). Cowichan Lake is approximately 30 km long and 3 km at its widest point, with an area of around 6,200 ha. Much of what we know about the species has come from studies in Mesachie Lake, which is much smaller (approx. 1.4 km and 59 ha) and drains into the southern end of Cowichan Lake. Coordinates for Mesachie Lake are: 48° 48’ 50” N, 124° 6’ 54” W. While there are no barriers to the sea (the Cowichan River empties on the east side of Vancouver Island), the species is non-anadromous.

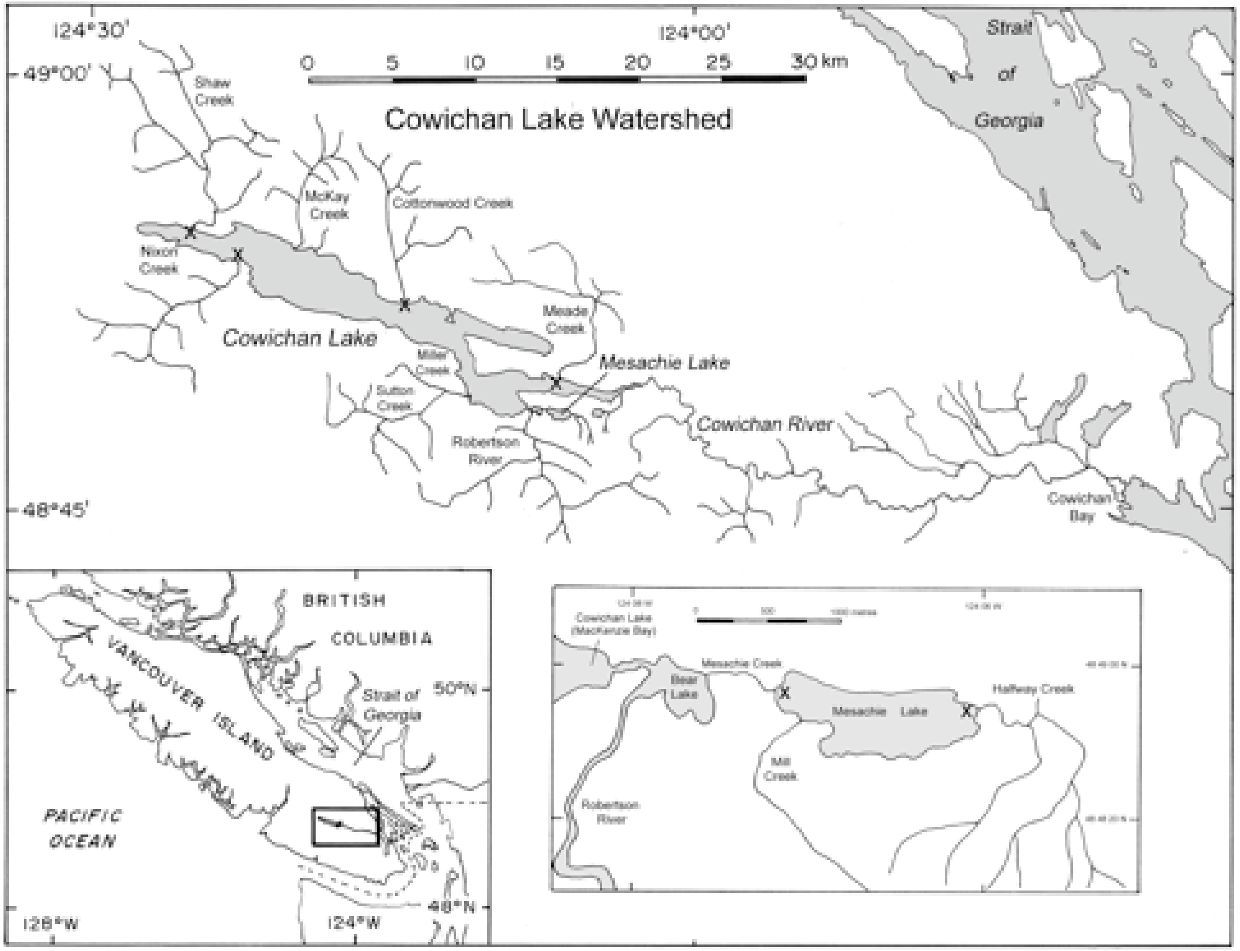

Figure 2. Map of Cowichan and Mesachie Lakes. Global range of Vancouver Lamprey courtesy Beamish and Wade (2008). X's indicate locations where Vancouver Lamprey have been found.

TAXONOMY

The lamprey in Cowichan and Mesachie lakes are presently considered to be a single population, although this could change with further collection and DNA analysis. Harris (2007) argues for the existence of multiple populations of Vancouver lamprey in Cowichan and Mesachie lakes, based on sampling evidence that shows ammocoetes to be widely distributed, and the assumption that dispersal from spawning sites is limited.

The species itself is a presumed freshwater derivative of the anadromous Pacific lamprey *L. tridentata*, isolated when lake drainage patterns changed around 10,000 years ago. As far as the mitochondrial genome goes, the two species are genetically indistinguishable (Docker et al. 1999), and McPhail (2007) describes its taxonomic status as “unclear.” More recently, ammocoetes collected in the system have been screened to identify microsatellite loci useful as high-resolution markers for future population and conservation genetic studies (Harris 2008). Several candidate markers were identified. Future studies may help resolve outstanding questions such as the number of populations of *L. macrostoma*, any gene flow between them, the genetic boundaries of units of conservation, and even a way of inferring dispersal of ammocoetes from spawning locations or between rearing habitats.

Beamish and Wade (2008) argue for its continued designation as a separate species (and for management that recognizes the importance of protecting its habitat) based on morphological differences and low probability of its interbreeding with *L. tridentata*. They stress that even though *L. tridentata* is often found in the Cowichan River, there is as yet no evidence for that species in Cowichan or Mesachie Lake.

Very few lake-feeding populations of *L. tridentata* are known, but more studies are needed to confirm whether *L. tridentata* does not migrate into Cowichan Lake (there is no physical barrier to migration). On current evidence it is reasonable to assume that all the ammocoetes found in studies on the lake shorelines were *L. macrostoma*. The same authors also note that the common name "Vancouver lamprey" implies some association with the city of Vancouver and has little meaning; the name is currently under review, along with a proposal to change it to "Cowichan lamprey" (Joy Wade, Fundy Aqua Services, Nanoose Bay, BC, pers. comm.)

ABUNDANCE

Neither total population size nor abundance specific to the various habitats are known. COSEWIC (2000) contains an estimate of 1,000-2,000 adults, a number that was not based on systematic sampling. Results of a trapping study in Mesachie Lake suggest the population may have substantially declined in the last fifteen years (Beamish and Wade 2008). The evidence on abundance from a more recent sampling of ammocoetes and adults is equivocal (Harris 2007, 2008). In these studies, which were carried out for the B.C. Ministry of Environment, wide distribution of ammocoetes throughout the system suggested that the species might be more abundant than previously assumed and that the estimate of 1,000-2,000 adults may be low; however, the difficulty in capturing adults during what is presently understood to be the spawning season could also be interpreted as evidence of declining numbers. Clearly there is a need for better estimates of adult abundance to fill this critical information gap, using mark and recapture methods during the spawning period, when adult lamprey can be trapped and marked. Ideally, such studies could be complemented by techniques like radio-telemetry to help in identifying spawning areas (Harris 2008). Ammocoete abundance could be further refined using artificial enclosures constructed in the field (Harris 2007).

There is no information available on trajectories for abundance, range or number of populations. Thirty years of informal records from the annual fishing derby on Mesachie Lake suggest decreased CPUE in recent years (Beamish and Wade 2008).

CURRENT OR RECENT LIFE HISTORY PARAMETERS

While the life history of Vancouver lamprey has not been extensively studied, we do have a rough picture of its habits that makes possible some qualitative predictions of life history parameters. Life span is unknown, but is likely longer than two years. In laboratory experiments, spawning was followed by death, which is the usual lamprey pattern (Larson 1980).

Lampreys have a larval stage called the ammocoete, which lives buried in stream or lake sediment until metamorphosing into free-swimming juveniles, and whose habitat requirements are important for survival over long periods. Ammocoetes of Vancouver lamprey have been collected from mid-September to mid-November (Beamish 1982) but this tells us little about when they actually emerge, because the ammocoete stage of Pacific lamprey can last up to seven years (Beamish and Levings 1991). Beamish (1982) estimates the minimum time between metamorphosis and spawning to be two years; more recently, that estimate has been extended to five years and older (Beamish and Wade 2008); the number is likely to remain an estimate, because the only way to really be sure of the duration of the ammocoete stage is to rear them in captivity. The relatively large size of the limited number of ammocoetes collected in Cowichan Lake (10-17 cm) argues for a similarly long larval lifespan (McPhail 2007). Clearly, estimating recruitment is difficult for a species where year classes can overlap like this. The length-frequency method is unreliable for aging ammocoetes (McPhail 2007).

Vancouver lamprey in spawning condition have caught between mid-May and late August, with a peak in mid-June, usually in gravel areas near the mouths of inlet creeks. Spawning nests were circular areas of cleaned gravel around 6-12 cm in diameter (Beamish and Wade 2008). Based on the observation that spawning occurs near stream inlets, a 2008 survey of putative spawning areas in both lakes used various adult capture methods (electrofishing, Fyke net and kick or drift net, guided by snorkel surveys) only caught six adult lamprey in three separate locations in the Cowichan Lake system (Harris 2008).

Fecundity of Vancouver lamprey is unknown. In Pacific lamprey in the lower Fraser system, fecundity ranged from 10,000 to 106,000 eggs per female (Pletcher 1963); these fish were, however, larger than the adult Vancouver lamprey recorded from Cowichan Lake.

If the ammocoete stage can last up to seven years, this suggests a total lifespan of around nine years. Egg and ammocoete survival are unknown, as is percent mortality during the juvenile and adults stages. Estimating productivity is therefore impossible; recourse to data from Pacific lamprey is not helpful, because the entire downstream migration and saltwater life segment—including associated sources of mortality—is missing in Vancouver lamprey.

A crude idea of natural mortality and yield per recruit can be obtained using the available information on maximum length, age at maturity and fecundity (Froese and Pauly 2008). The calculated natural mortality of 0.32/yr suggests a species of medium resilience, with a minimum population doubling time of 1.4-4.4 years; note, however, that mortality arrived at this way is under-estimated for eel-like fishes (Froese and Pauly 2008). Compare, for example, the three-spine stickleback, which, while having a higher natural mortality, are highly resilient with a doubling time of 15 months. A major problem in calculating productivity and population resilience for Vancouver lamprey is the uncertainty associated with not knowing the duration of the ammocoete stage; in other words, ammocoetes represent several year-classes.

Adult Vancouver lamprey in Cowichan and Mesachie lakes readily attack resident fishes, including salmonids, although we don't know which prey they prefer. While landing of fish with lamprey attached is uncommon, all such lamprey examined have been *L. macrostoma* (Beamish and Wade 2008). Trapping studies show that coho salmon smolts leave Mesachie Lake heavily scarred from lamprey attacks. The number and frequency of lamprey attacks on sport-caught salmonids may represent an important data set that contributes to our understanding of the species' abundance; gathering this information through angler surveys offers an opportunity to combine public engagement with data collection. Any information-gathering that targets the interaction between lamprey and salmonids needs to take into account the past and ongoing levels of salmonid stocking in both lakes (some idea of stocking can be obtained from records at gofishbc, but data for the Cowichan/Mesachie system are incomplete). Prey population size is presently unknown for both Mesachie and Cowichan lakes.

HABITAT REQUIREMENTS AND USE PATTERNS

There is enough known about the life history of the species to generally describe the physical characteristics of habitat required by its various life stages. Much of what we know is presently based on studies in Mesachie Lake, the smaller of the two bodies known to contain the species.

Adults

Adult Vancouver lamprey are presumed to feed on resident and migratory fish species in both lakes, and are believed to enter tributary streams to a short distance only, and then only to spawn (Beamish 1982). It seems reasonable to assume, based on the known depth preferences for Pacific lamprey in the ocean (they have been caught at 150-200 metres in the Strait of Georgia; Beamish 1980), that feeding in the lake can occur throughout the water column. Beamish (1982) suggested that adults spawned on shallow gravel bars in the nearshore areas of the lake, constructing nests in a fashion similar to that of Pacific lamprey at depths around 15 cm (COSEWIC 2000). Gravel is assumed to provide adequate water flow. The finding of ammocoete larvae in the lower 100 metres of some inlet streams also suggests that adults can spawn in these areas (Beamish 1982). In summary, adult Vancouver lamprey probably utilize the lake margin and tributary stream entries for reproduction, and the entire water column for feeding, with the major uncertainties being in identifying any preferred spawning areas and their depths, as well as a lack of knowledge of water quality tolerances.

Ammocoete Larvae

Ammocoetes are presumed to burrow into fine silt in the littoral zone or in the first hundred metres of inlet streams shortly after hatching, where they filter-feed on microscopic algae and organic detritus for an unknown period before emerging as immature adults. Ammocoetes were found in shallow areas along the shore of Mesachie and Cowichan lakes, in silt over sand or fine woody debris, as long as silt was no deeper than 10 cm. In Mesachie Lake they were mostly found along the shoreline close to the inlet stream, with very few near the outlet stream (Beamish and Wade 2008). A similar distribution picture emerges from sampling in Cowichan Lake (which is much more limited than in Mesachie): near, or less than 100 m into, inlet streams. In a more recent study, ammocoetes were captured by electrofishing in 16 locations in the Cowichan/Mesachie system, and observations on what might be productive ammocoete habitat were made. The presence of ammocoetes was best predicted by areas with soft, fine sediments or sand, with an organic component such as decomposed wood and leaves. No larvae were found in areas with coarse sand and gravel, which is considered to be the best spawning habitat and usually occurs near the mouths of tributaries (Harris 2007). There is uncertainty about the habitat requirements of post-larval lamprey between their metamorphosis (emergence) in the fall and the beginning of feeding the following spring (Beamish 1982). COSEWIC (2000) suggests the young adults overwinter in gravel.

Critical Habitat

Habitat that is important or critical for Vancouver lamprey must be identified according to life stage. Until recently, most of our knowledge of Vancouver lamprey biology and habitat use came from Mesachie Lake. Critical spawning and rearing habitat in Mesachie Lake includes the shallow covered lakeshore gravel areas near the mouths of streams that flow into both lakes, extending 100 m up stream. This substrate contains silt, gravel and fine woody debris. River discharge level may also be important during egg incubation. The recent work of Harris (2007) emphasizes the importance of fine substrate with organic debris, and extends our knowledge into Cowichan Lake to demonstrate that, based on the use of electrofishing gear, the species is also widely distributed there. A strong argument might thus be made for defining such areas as critical ammocoete habitat.

It is not yet possible to define critical habitat for the adult stage; however, since the species is presumed to feed throughout the water column. Mesachie and Cowichan Lakes, including the entire water column and submerged gravel areas, should be considered important habitat in their entirety pending further studies on the natural history of the species.

POPULATION AND DISTRIBUTION TARGETS FOR RECOVERY

In the absence of sufficient life history information, population census or evidence of decline, the appropriate target becomes maintenance of a self-sustaining population within the known distribution. Establishment of quantitative benchmarks is impossible without increased research and monitoring effort.

EXPECTED POPULATION TRAJECTORIES

Rough comparison of trapping effectiveness in Mesachie Lake between the 1980s and studies done in 2008 suggests a decline in population. In the absence of a quantitative recovery target, however, it is not possible to describe the expected population trajectory.

RESIDENCE REQUIREMENTS

While adult Vancouver lamprey are not believed to guard their egg nests, they expend energy in creating spawning nests by carrying gravel in their mouths. Spawning nests should thus be considered short-term residences. An argument can also be made that the ammocoete larval stage, whose duration may be several years, has a residence requirement for silty substrate in which to construct burrows. As noted above, the depth to which these burrows are found, and any preferred locations within the lake, remain uncertain, as do any movements made by the ammocoetes.

II: SCOPE FOR MANAGEMENT TO FACILITATE RECOVERY

PROBABILITY THAT THE RECOVERY TARGETS CAN BE ACHIEVED

It is difficult to make predictions in the absence of data on population size and a quantitative recovery target, and the likelihood of maintaining a self-sustaining population of Vancouver lamprey, even in the absence of unforeseen threats other than the ones described below, cannot be estimated. The decline in abundance suggested by recent sampling warrants increased caution. Although Vancouver lamprey appears to be a medium-productivity species, it has withstood sustained timber extraction (see below) using methods (booming in the lake; logging camps on the foreshore) that probably caused more damage than do today’s. The only known source of direct mortality (bycatch, see below) could be further reduced.

MAGNITUDE OF EACH MAJOR POTENTIAL SOURCE OF MORTALITY

Vancouver lamprey owes its *SARA* listing primarily to its restriction to a small geographic area; evidence of population decline suggested by trapping studies needs to be confirmed by mark-recapture research (Beamish and Wade 2008). Cowichan and Mesachie Lakes are popular recreation areas where residential development is increasing. Both watersheds have been heavily logged historically, and timber extraction continues. The main threats to Vancouver lamprey are:

Bycatch in the recreational fishery

The only known direct mortality on Vancouver lamprey occurs when anglers kill adult lamprey attached to a trout or salmon they have caught in the lake. The percentage of lamprey that are actually attached to salmonids when caught is not known, nor is the number that fall off when fish are caught. The population effect of killing angled lamprey is unknown, although the Vancouver Lamprey Recovery Strategy considers it capable of affecting the population (Vancouver Lamprey Recovery Team 2007). The likelihood of mortality from this threat is high but its severity cannot be quantified until surveys are conducted to determine the degree of mortality.

Residential development and recreation

Residential development inevitably increases water withdrawal, and can also degrade water quality through addition of pollutants or changes in water chemistry. Foreshore can be disrupted by pier construction, and water quality is affected by pollution from marine engines. There are no known water quality issues in either lake (Vancouver Lamprey Recovery Team 2007). Uncertainty lies in lack of knowledge of lamprey use of littoral areas for spawning and ammocoete residence, and the effects of accelerated development in recent years. The threat cannot currently be quantified.

There has been significant development on Mesachie Lake in the past fifteen years, including two new houses close to the spawning area at the inlet stream (this important habitat is on private property) and construction of a large summer camp for children on the site of the former lumber mill. New lakeshore residents have created new beaches with trucked-in fine gravel; these areas may represent additional spawning area (Beamish and Wade 2008). On Cowichan Lake, much of the new residential development is taking place on land purchased from tree farm license-holders (Joy Wade, Fundy Aqua Services, Nanoose Bay, BC, pers. comm.).

Forestry

Logging has been the main economic activity in the Cowichan Lake region since settlement in the late 1800s; the area had a ready supply of timber and a convenient river route for transport to the coast (river transport was replaced by the railway in 1912, and finally by logging roads). The communities of Cowichan Lake and Mesachie Lake owed their survival to logging; at one time, large logging camps occupied the lake foreshore, and much of Cowichan Lake was logged to the water. During the period of intensive timber extraction, Mesachie Lake was used as a booming ground for the nearby lumber mill (Joy Wade, Fundy Aqua Services, Nanoose Bay, BC, pers. comm.). Vancouver lamprey appear to have weathered this intensive resource extraction (now somewhat reduced) for more than a century, although the lack of abundance records means there is no data that would allow the determination of whether or not logging caused any impact on the population. The current threat to the population from logging is likely low and unquantifiable; it is not expected to increase.

Water withdrawal and water quality

Outflow of Cowichan Lake into the Cowichan River is regulated by a weir to release water uniformly through the summer dry season and to facilitate operation of the Catalyst Paper pulp mill in Crofton. The Vancouver Lamprey Recovery Team (2007) analyzed the annual range in lake elevations before and after construction of the weir in 1957 and concluded that storage and diversion posed at most a minor threat to Vancouver lamprey. Neither licensed nor unlicensed water use is a substantial threat to the species in the near term in Cowichan Lake, but may be for Mesachie Lake. Increased summer drawdown of water for residential use has the potential to affect water levels on Mesachie lake (Beamish and Wade 2008).

Prey availability

The prey population size and trends in both Mesachie and Cowichan lakes are unknown. In order for this species to survive and thrive, it needs a consistent source of prey. We do not presently know the preferred prey for *L. macrostoma*. Some of this knowledge could be obtained through angler surveys. Neither Cowichan nor Mesachie Lake appears to have been stocked with salmonids (gofishbc.com), although records are incomplete before 2004.

LIKELIHOOD THAT THE CURRENT QUANTITY AND QUALITY OF HABITAT IS SUFFICIENT TO ALLOW POPULATION INCREASE

The shallow, covered gravel areas near the mouths of the inlet streams to Mesachie and Cowichan Lakes serve as spawning, egg incubation and ammocoete stage habitat (Beamish and Wade 2008). Habitat in Mesachie Lake is better studied than in Cowichan Lake; each must be considered separately. Flow rate in the stream is probably an important habitat attribute; lower flow can result in uncovered gravel areas and restricted spawning. Because the known spawning areas are discontinuous pockets of raised gravel deposition, low lake levels may similarly restrict spawning areas. Because the ammocoete life stage is thought to last five or more years, this habitat must be maintained for long periods.

Given the low esteem in which lamprey are popularly held and the equivocal evidence of any trends in abundance, there are no strong arguments that population can or should increase. It is not currently known what factors limit the abundance of Vancouver lamprey, although one likely determinant is availability of food. The lamprey population will probably continue to find equilibrium with its prey; the Vancouver Lamprey Recovery Team identifies this relationship as one meriting further research. COSEWIC (2000) suggests that the species coexists with its salmonid prey and that up to 50% of the salmonids caught in Mesachie Lake had evidence of non-lethal predation by lamprey. It is unknown if habitat is a significant limiting factor.

MAGNITUDE BY WHICH CURRENT THREATS TO HABITATS HAVE REDUCED HABITAT QUANTITY AND QUALITY

The effects of the most significant past threat (intensive timber harvest close to the lake, and use of foreshore for logging camps and booming) are impossible to judge from today's perspective, but they are likely to have been indirect, through affecting the numbers of salmonid prey species that are more susceptible to such disturbances in the watershed. Alteration or elimination of spawning and rearing habitat as a result of increased residential foreshore development are concerns whose magnitude are currently impossible to judge, because it is not known whether habitat availability limits the population; food supply, for example, may be just as important.

III: SCENARIOS FOR MITIGATION AND ALTERNATIVE ACTIVITIES

FEASIBLE MEASURES TO MINIMIZE/MITIGATE THE IMPACTS OF ACTIVITIES THAT ARE THREATS TO THE SPECIES AND ITS HABITAT

Threats from forestry are likely to be lower than in the area's boom years. The methods and regulations used to mitigate forestry impacts reflect the ownership of land adjacent to inlet streams in Cowichan and Mesachie Lakes. Riparian forest practices that minimize effects of logging on aquatic species are also contained in the Forest and Ranges Practices Act, which applies to Crown lands. Judging the potential effect of the provisions in the Forest and Ranges Practices Act on lamprey would require a comprehensive inventory of spawning and rearing habitat, linked to a survey of land ownership in the identified areas.

With regard to the only known direct mortality, the Freshwater Fishing Regulations published annually by the B.C. Ministry of Forests, Lands, and Natural Resource Operations (2008) contains an advisory on "Protected Species" (15 such species are listed in the 2008 Regulations, including Vancouver lamprey). The advisory notes that catching or killing a protected species is illegal. On its own, the advisory seems unlikely to provide much of a deterrent and should not be expected to reduce mortality significantly. Angler awareness could be substantially raised using proven outreach methods such as signs and leaflets, in which case a further reduction in mortality might be expected. Angler participation in a survey concerning the number of lamprey attacks on salmonids could be expected to raise awareness while at the same time contributing important insight into any population fluctuations.

Threats from residential development are difficult to quantify because of uncertainty regarding habitat use for larval and adult stages; the threats and their magnitude are different for Mesachie and Cowichan Lakes. Foreshore development could have a serious impact on spawning habitat and the larval (ammocoete) stage; mitigation would involve careful design of nearshore structures to avoid destroying this habitat. The Riparian Areas Regulation contained in the Fish Protection Act, while applying only to private lands and Crown land used for private purposes, is intended to reduce the impact of residential, commercial, and industrial development, and is in force in the Cowichan Valley. Construction of new beaches near residential developments may be a form of inadvertent mitigation, but differences in gravel size between these beaches and identified spawning areas suggest caution in assuming such beaches constitute alternative spawning habitat.

The lack of information on lamprey abundance and the apparent restriction of its critical habitat to certain areas of the lakeshore and inlet streams suggest that lethal sampling of ammocoetes or adults for research be carefully designed to limit any potential harm to the population. Killing limited numbers of adults or larvae in order to understand their life history better (and thus increase our ability to protect them) is a justifiable risk. Harm for any other purpose is not warranted.

REASONABLE ALTERNATIVES TO THE ACTIVITIES THAT ARE THREATS TO THE SPECIES AND ITS HABITAT

The alternative to bycatch mortality in the recreational fishery is to prohibit the fishery, a measure that would be counterproductive and would remove the opportunity to gather important abundance data through cooperative programs with anglers. Reduction in bycatch mortality will be more easily achieved through awareness. Lamprey depend on angled species for their prey. Alternatives to residential development and forestry are less likely to ensure lamprey sustainability than are the measures for minimizing impact already described.

As an endemic species, Vancouver lamprey is considered to be irreplaceable. The biological feasibility of a “rescue effect” by an introduced population of Pacific lamprey is debatable. McPhail (2007) and COSEWIC (2000) mentions several naturally occurring Pacific lamprey populations that may in fact be permanent freshwater residents, including those in Sakinaw Lake, Village Bay Lake and West Lake; all are coastal lakes. But when Pacific lampreys become landlocked through human intervention, they rarely if ever establish self-sustaining populations in fresh water (Beamish and Northcote 1989). Pacific lamprey exist in Cowichan River, but it is not known if they occur in the lake (Beamish 2001). The lack of clarity here is a good example of the need for more research on the life history of Vancouver lamprey.

In general, discussion of alternative activities and their impacts on populations must rest on adequate knowledge of the species’ life history, habitat use, abundance and susceptibility to various causes of mortality. None of these are well enough known for Vancouver lamprey; further studies on all of them, including a monitoring program, are recommended by the Vancouver Lamprey Recovery Team (2007).

REASONABLE AND FEASIBLE ACTIVITIES THAT COULD INCREASE THE PRODUCTIVITY OR SURVIVORSHIP PARAMETERS

To describe productivity of Vancouver lamprey we need to know its intrinsic rate of population growth; Froese and Pauly (2008) estimate a value of 1.08/yr. based on an assumed rate of F_{MSY} (fishing mortality at maximum sustainable yield). If exploitation (which in the case of Vancouver lamprey is represented by angler-caused mortality) were better defined, various scenarios for lamprey productivity could be produced.

An alternative approach acknowledges the lack of species-specific abundance or life history information that makes it impossible to model lamprey population trajectory or its responses to human activities. This approach, developed in DFO Central and Arctic Region, uses a combination of species-specific information and general life history predictors to evaluate “elasticities”, which may be defined as the proportional changes in population growth rate that would result from a given change to a stage-specific survival rate. Depending on the life history characteristics of the species, an elasticity analysis might reveal that one or more life stages were highly sensitive, meaning that harm during these stages would have a large impact on the population’s growth rate (Velez-Espino and Koops 2007). The elasticity analysis approach, which derives from a population matrix model, has also proven useful in another data-poor freshwater fish species, mountain sucker *Catostomus platyrhynchus*, where analysis strongly suggested high population sensitivity to decreases to survival in the early life stages (Belica and Nibbelink 2006). It is important to note, however, that testing the sensitivity of a given life stage by manipulating a mathematical model says nothing about how easy it is for that parameter to change in nature; in other words, the method gives us valuable insights about the relative sensitivities of different life stages, but the actual range of variability for each parameter will not be the same across the life cycle. In the analysis, each parameter is equally valued, a situation that change in real life.

To assist in dealing with such data-poor species, Velez-Espino et al. (2006) summarized life history for 88 North American freshwater fish species to seek generalizations and predictive relations. Unfortunately no Petromyzontidae were included in their analysis. However, Velez-Espino et al. (2008) recently conducted an elasticity analysis for Great Lakes lamprey (*P. marinus*), whose life history resembles Vancouver lamprey in that the age of metamorphosis is 6-8 years and the parasitic stage lasts 1-2 years. Fecundity is about 60,000 eggs/female. The results of their analysis showed that the elasticity of each of the major vital rates was similar (elasticity of ammocoete survival was higher for some variations of the model). This means that there is no single critical stage that is influential in determining population growth rates. Harm (expressed as a proportional change in a stage-specific vital rate) to *any* life stage will have a similar effect on population growth.

In the case of the Great Lakes lamprey, the “conservation problem” is the reverse of that for Vancouver lamprey; control rather than population stability is the goal. Managers are attempting to suppress lamprey by actions that reduce survival or the size of the spawning stock. Velez-Espino et al. (2008) note that population growth rate can be reduced to zero through a 40% increase in juvenile mortality. In Vancouver lamprey, however, a key unknown is the relation between habitat and stage-specific vital rates. This step is needed to be able to relate any changes in habitat to the “allowable” increase in mortality as indicated by the elasticity analysis.

Until the collection of detailed life history information and population parameters for Vancouver lamprey advances, we may draw upon Velez-Espino et al. (2008) to conclude that significant harm to *any* of the life stages of the Vancouver lamprey may threaten the existence of the population. A thorough survey of habitat use for the population seems required so that harm in the form of habitat alteration can be avoided

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