FINAL
Coastal, Columbia, and Snake Conservation Plan for Lampreys in Oregon

Pacific Lamprey
Western River Lamprey
Western Brook Lamprey
Pacific Brook Lamprey

OREGON DEPARTMENT OF FISH AND WILDLIFE
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ODFW Mission

To protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations

Acknowledgments

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Executive summary

- The *Coastal, Columbia, and Snake Conservation Plan for Lampreys in Oregon* (CPL) covers four species:
    - Pacific Lamprey (anadromous)
    - Western River Lamprey (anadromous)
    - Western Brook Lamprey (resident)
    - Pacific Brook Lamprey (resident).
- The purpose of the CPL is to identify, acknowledge, and support actions needed to conserve lampreys in the service of the mission of the Oregon Department of Fish and Wildlife (ODFW)[1]. The CPL identifies management strategies to address factors limiting lampreys, and research, monitoring, and evaluation (RME) needed to fill data gaps and inform future status assessments for them. These management strategies and RME are for ODFW to implement in coordination with other entities and landowners.
- Pacific Lamprey is important to the culture of Native American tribes. Concerns expressed by various tribes about Pacific Lamprey in the 1980s and 1990s precipitated increased research and management actions for this species. These efforts have been led by various tribes, the U.S. Fish and Wildlife Service (USFWS), and other entities to benefit Pacific Lamprey.
- Many of the actions called for in the CPL are ambitious and ODFW does not have the capacity to execute these alone. Identifying, acknowledging, and supporting collaborations with tribes, watershed councils, the USFWS, and others is essential to implementing actions identified in the CPL. These actions build upon existing and new efforts being carried out by the aforementioned entities to benefit Pacific Lamprey and their habitats.
- The CPL includes two scales: 1) population stratum and 2) Species Management Unit (SMU). Biological status and management actions are determined at the stratum scale. Seven strata exist for the lampreys covered in this plan (Table E1.1). The conservation unit at which state listing (ESA and sensitive species status) is determined is the SMU scale. The SMU for all lampreys is the State of Oregon.
- Pacific Lamprey is the largest and most widespread lamprey in Oregon. The biology and distribution of the other three lampreys is less well known. Sufficient data exist to assess three measurable criteria for Pacific Lamprey, including distribution, adult abundance trends, and connectivity. These criteria were analyzed to determine current status. Current status for Pacific Lamprey ranged from “absent” to “prevalent” across seven strata, with an overall SMU status of “sensitive” (Table E1.1).
- Insufficient data prevented assessments of the measurable criteria for Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey. This resulted in the overall SMU status of “sensitive” for these three species.
- The Oregon Department of Fish and Wildlife has identified two desired outcomes:

[1] “*To protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations.*”

  - maintain and, where possible, improve the desired status of Pacific Lamprey in each stratum by at least one level above the current status to improve the SMU status to "strong-guarded" (Table E1.1)
  - improve information on the other three lampreys so that their status can be determined in the future (Table E1.1).

- Based on current best knowledge, ODFW identified key limiting factors that are causing the gap between current and desired status. These key limiting factors were identified through interviews with ODFW district staff, literature reviews, and professional judgment. The severity and geographical extent of these limiting factors was ranked. The top five key limiting factors, in order of relative impact are: 1) access (passage), 2) water quantity, 3) water quality, 4) physical habitat, and 5) predation by other species (Table E1.1).
- Three complex, large-scale threats exacerbate these limiting factors: 1) climate change, 2) estuary and ocean conditions, and 3) development relative to human population growth (Table E1.1). These threats will have pervasive and interactive impacts to ecosystems used by lampreys. This suggests the need to monitor climate change impacts to lampreys; improve understanding of how estuarine and ocean conditions will affect recruitment of anadromous lampreys; improve predictions of how development will affect freshwater habitats of lampreys; and improve our understanding of the interactive effects of these threats on factors limiting lampreys.
- A combination of funding, adaptive management, and well-coordinated collaborations among entities will be required to address limiting factors to lampreys and to offset additional impacts of complex, large-scale threats.
- Eight management strategies were identified to address key limiting factors and threats (presented in order of priority in Table E1.1). The CPL calls for an adaptive approach to implement new information and the best available science to improve these management strategies.
- Nine RME were identified to address key unknowns and management strategies for lampreys (presented in order of priority in Table E1.1).

Table E1.1. Summary of the statuses, key limiting factors and threats, management strategies, research, and needs for lampreys. "Baseline" refers to status designations for lampreys, by the state of Oregon, prior to this Conservation Plan for Lampreys. "Baseline" includes an interim status assessment of risk to extinction (ODFW 2005) and species sensitivity (ODFW 2016). SMU = Species Management Unit; composed of up to seven population strata.

	Pacific Lamprey		Western River Lamprey		Western Brook Lamprey		Pacific Brook Lamprey	
Baseline	Interim status: At risk		Interim status: *Not assessed*		Interim status: At risk		Interim status: *Not assessed*	
	State listing: Sensitive		State listing: Sensitive		State listing: Sensitive		State listing: *Not listed*	
Population Strata: Current Status	Rogue/South Coast	Common			Rogue/South Coast	*Undetermined*		
	Coastal	Prevalent	Coastal	*Undetermined*	Coastal			
	Lower Columbia	Common	Lower Columbia		Lower Columbia		Lower Columbia	*Undetermined*
	Willamette	Common			Willamette		Willamette	
	Mid Columbia	Limited	Mid Columbia	*Undetermined*	Mid Columbia			
	Lower Snake	Rare						
	Upper Snake	Absent						
SMU: Current Status	***Sensitive***		***Sensitive***		***Sensitive***		***Sensitive***	
SMU: Desired Status	***Strong-Guarded***		***Strong-Guarded***		***Strong-Guarded***		***Strong-Guarded***	
Key Limiting Factors	**1) Access (passage and screening at artificial obstructions)** **2) Water quantity (reduced flows, flow management)** **3) Water quality (high water temperature, sedimentation)** **4) Physical habitat (stream and floodplain degradation)** **5) Predation by other species (particularly non-native fishes)**							
Threats	– Climate change, estuary and ocean conditions, and development due to population growth							
Mgmt. Strategies (*status for ODFW*)	1) Education & outreach (*New*) 2) Passage & screening (*New & Existing*) 3) Protect & restore habitat (*Existing*) 4) Water conservation (*Existing*)				5) Translocation (*New*) 6) Establish in-water Best Management Practices (*New*) 7) Modify non-native angling regulations (*New & Existing*) 8) Pinniped management (*Existing*)			
Research, Monitoring & Evaluation	1) Improve information on lamprey distribution (*Monitor; New & Existing*) 2) Prioritize artificial obstructions for passage & screening (*New Evaluate*) 3) Inform passage & screening requirements (*New Research*) 4) Improve biological knowledge (*New Research & Monitoring*) 5) Estimate take (*Monitor & Evaluate; New & Existing*)				6) Assess complex, large-scale threats (*New Research & Evaluation*) 7) Assess translocation (*Monitor & Evaluate; New*) 8) Estimate adult abundance (*Monitor & Evaluate; New & Existing*) 9) Monitor diversity (*New Monitoring*)			
To Do	– Address limiting factors through implementation of new and existing management strategies – Address unknowns through implementation of existing and new research, monitoring, and evaluation – Assess future status with greater certainty through improved information and techniques							

Chapter 1: Introduction

The CPL covers four species of lamprey (Table 1.1): Pacific Lamprey (anadromous), Western River Lamprey (anadromous), Western Brook Lamprey (resident), and Pacific Brook Lamprey (resident). These species collectively occur in Oregon's coastal and Columbia River basins. This plan does not focus on the Klamath River drainage, where at least six other species of lampreys occur (Table 1.1). Some of these Klamath lampreys are dealt with in other management plans (including the Miller Lake Lamprey Conservation Plan, OAR 635-500-3885, and the Klamath River Basin Fish Management Plan, OAR 635-500-3600 through 635-500-3880).

In support of ODFW's mission to protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations, conservation plans are called for in the Native Fish Conservation Policy (OAR 635-007-0502 through 0509; ODFW 2003), which has three goals:

- prevent the serious depletion of the aforementioned lamprey species through various management actions
- maintain naturally-produced lampreys throughout Oregon, taking full advantage of the capacity of natural habitats to produce these lampreys, to provide ecological, economic, and cultural benefits to all Oregonians
- provide sustainable opportunities for take, consistent with the conservation of naturally-produced native fish.

Consistent with ODFW's mission and Native Fish Conservation Policy, the CPL identifies lamprey conservation needs. It does this by assessing current status, desired status, and factors limiting lampreys. These are used to identify management strategies and RME needed to fill data gaps and inform future status assessments for these lampreys.

Prior to the CPL, numerous important efforts have already occurred and are occurring by tribes, the USFWS, USACE, ODFW, and other entities to benefit Pacific Lamprey across their range and in Oregon (Table 1.2; CRITFC 2011; Luzier et al. 2011; CRITFC et al. 2018; USFWS 2018). The CPL acknowledges and supports this important work and identifies additional efforts needed across Oregon. Although some of the existing and new efforts for Pacific Lamprey can benefit and shed light on the biology of other lampreys addressed in the CPL, additional work will also be needed to benefit Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey.

ODFW does not have the capacity to implement the ambitious management strategies and RME called for in the CPL alone. Given existing leadership and efforts by tribes, the USFWS, and others, ODFW will cooperatively support these existing efforts and collaboratively initiate new ones to benefit lampreys and their habitats, as guided by the CPL. Identifying, supporting, and acknowledging collaborations with tribes and other partners interested in lamprey conservation will be essential to implementing the strategies and RME called for in this plan.

Table 1.1. Lamprey species of Oregon. The four species covered in the CPL are noted in **bold.** Details on the biology of these lampreys are discussed in Chapter 2. The scientific names of these and other animals mentioned in the CPL are provided in Appendix 1.

Common name
– **Pacific Lamprey**
– **Western River Lamprey**
– **Western Brook Lamprey**
– **Pacific Brook Lamprey**
– Northern California Brook Lamprey
– Miller Lake Lamprey
– Pit-Klamath Brook Lamprey
– Klamath River Lamprey
– Klamath Lake Lamprey
– Goose Lake Lamprey

BACKGROUND

The first lamprey found in the fossil record dates back 360 million years ago (Gess et al. 2006). This ancestral lamprey looks very similar to lamprey species alive today (Gess et al. 2006; Janvier 2008). Lampreys have lived through at least four global mass extinction events (Barnosky et al. 2011), suggesting they have been resilient to environmental upheavals that extirpated many other species. A total of 41 – 44 lamprey species are recognized worldwide (Potter et al. 2015; Maitland et al. 2015). At least 10 of these species are native to Oregon, making Oregon a “hot spot” of lamprey diversity (Potter et al. 2015; Markle 2016; Table 1.1).

Pacific Lamprey was the first of the four lampreys covered in the CPL (Table 1.1) to be described by science (Table 1.2). One-hundred and twenty-two years later Western River Lamprey was the next to be described, followed seven to 15 years later by Western Brook Lamprey and Pacific Brook Lamprey (Table 1.2). Biologists soon considered Pacific Brook Lamprey to be the same species as Western Brook Lamprey. However, recent morphological and genetic information suggests that Pacific Brook Lamprey is a unique species (Reid et al. 2011).

Pacific Lamprey is an important part of the culture of Native American tribes that use them for ceremonial, medicinal, and food purposes (Downey et al. 1996; Close et al. 2002, 2004; Petersen-Lewis 2009; CRITFC 2011; Sheoships 2014). Harvest of Pacific Lamprey sometimes referred to as “eels” in the vernacular, has occurred for thousands to tens of thousands of years (Downey et al. 1996; CRITFC 2011). In the 1980s and 1990s concerns by Native American tribes over the biological status of Pacific Lamprey led them to champion their importance and urge actions to stop their decline. In 1993 ODFW listed Pacific Lamprey as a “sensitive” species. By 1996 the Oregon Fish and Wildlife Commission (OFWC) approved restrictions on harvest and harvest methods of Pacific Lamprey. In 2002 the OFWC approved a ban of commercial harvest on Pacific Lamprey (Table 1.2). In 2003 interest in the plight of Pacific Lamprey, Western Brook Lamprey, and Western River Lamprey culminated in a petition to list these species under the Endangered Species Act (ESA 1973). The 90-day finding by the U. S. Fish and Wildlife Service (USFWS) concluded that listing was not justified, due to two factors: 1) a paucity of information on the biology of these lampreys and threats to them, and 2) a lack of population structure in Pacific Lamprey (USFWS 2004; Table 1.2).

Historically lampreys have not been a focus for research and monitoring (Close et al. 2002; Kostow 2002; Moser et al. 2007; Mesa and Copeland 2009; Clemens et al. 2017a). However, interest in lamprey conservation, particularly for Pacific Lamprey, has increased dramatically over the last two decades. An increasing number of conservation plans, information reviews, highlights of information gaps, and scientific and management actions have occurred during this period (Table 1.2). Of particular importance to the Snake and Columbia river basins (and therefore large parts of Oregon), are the Tribal Pacific Lamprey Restoration Plan (TPLRP) and the "Master Plan: Pacific Lamprey Artificial Propagation, Translocation, Restoration, and Research" ("Master Plan") set forth by the Columbia River Inter-Tribal Fish Commission and some of its member tribes (CRITFC 2011; CRITFC et al. 2018). The federally-coordinated Pacific Lamprey Conservation Initiative (PLCI) is a regional strategy that covers California, Oregon, Idaho, Washington, and Alaska (Luzier et al. 2009 and 2011; USFWS 2012).

The TPLRP for the Columbia River Basin was written by the Columbia River Inter-Tribal Fish Commission (CRITFC), which is composed of four member tribes: the Nez Perce Tribe, the Confederated Tribes of the Umatilla Indian Reservation, the Confederated Tribes and Bands of the Yakama Nation, and the Confederated Tribes of the Warm Springs Reservation of Oregon. This plan originated from tribal lamprey summits (Table 1.2), with the goals of halting the decline of Pacific Lamprey, and restoring them throughout their historical range "*in numbers that provide for the ecological integrity and sustainable tribal harvest*" (p. iv in CRITFC 2011). The TPLRP focuses on actions to address key uncertainties and address threats.

Six objectives were identified in the TPLRP as important to restoring Pacific Lamprey, which are stated here verbatim: 1) Improve lamprey mainstem passage, survival and habitat; 2) Improve tributary passage and identify, protect, and restore tributary habitat; 3) Supplement/Augment interior lamprey populations by reintroduction and translocation of adults and juveniles into areas where they are severely depressed or extirpated; 4) Evaluate and reduce contaminant accumulation and improve water quality for lamprey in all life stages; 5) Establish and implement a coordinated regional lamprey outreach and education program within the region; and 6) Conduct research, monitoring and evaluation of lamprey at all life history stages. The Master Plan identifies specific actions for supplementing and augmenting basins in the interior Snake and Columbia rivers through release of artificially-propagated Pacific Lamprey and translocation of adult Pacific Lamprey. The Master Plan also identifies the use of "control" streams (those for which hatchery releases and translocations will not be occurring) with which to compare various biological responses of these actions (CRITFC et al. 2018).

The PLCI is driven by partnerships to improve the status of Pacific Lamprey throughout its range in the United States. Through this initiative the partners coordinate and implement RME, conservation, and restoration actions. The PLCI is composed of an assessment (Luzier et al. 2011), a conservation agreement (USFWS 2012), and regional implementation plans with collaborations among multiple partners (USFWS 2012, 2015, 2018). The conservation agreement is a cooperative effort among entities to improve habitats, reduce threats, and improve the population status of Pacific Lamprey. Interest in lamprey across many sectors has grown and ODFW is one of many signatories to the Pacific Lamprey Conservation Agreement (USFWS 2012).

In 2016, realizing that its involvement in lamprey management required a greater focus, ODFW created a position dedicated to lamprey conservation and management. This position has greatly increased ODFW's capacity to conduct a variety of different lamprey-specific work, collaborate with others involved in lamprey actions, and develop the CPL that will focus ODFW's priorities in adaptive management strategies and research to conserve lampreys.

Table 1.2. Timeline of key actions for lampreys covered in the CPL. Adapted from Clemens et al. (2017a).

Year	Action	Citations
1836	Pacific Lamprey from Willamette River Basin described as new species	Gairdner in Richardson et al. (1836)
1958	Western River Lamprey re-described as a unique species	Vladykov and Follett 1958
1965	Western Brook Lamprey described as a new species	Vladykov and Follett 1965
1973	Pacific Brook Lamprey from Clackamas River described as new species	Vladykov 1973
1993	Pacific Lamprey listed as a sensitive species in Oregon	Kostow 2002; ODFW 2016; OCS 2017
1994	Due to tribal concerns, Northwest Power and Conservation Council (NWPCC) directs lamprey work	
1994	First tribal lamprey project initiated	
1995	Status report of the Pacific Lamprey in the Columbia River basin	Close et al. 1995
1995[a]	Formation of Columbia River Basin Lamprey Technical Workgroup	
1996	Harvest and harvest methods restricted in Oregon	ODFW 2006
1999	After 30 year hiatus, adult daytime counts at Bonneville Dam resume	
1999	Umatilla River Basin recovery plan developed, approved and implemented	
2000	Adult translocation begins in the Umatilla River, Oregon	Close 2000
2002	Commercial harvest of lamprey banned in Oregon	
2003	Petition to list several lamprey species under the Endangered Species Act	USFWS 2004
2004	Western Brook Lamprey listed as a sensitive species in Oregon	ODFW 2016; OCS 2017
2004	Finding that ESA listing not warranted	USFWS 2004
2004[b]	Columbia River Inter-Tribal Fish Commission's Lamprey Summit I	
2005	Critical uncertainties for Pacific Lamprey document	CRBLTWG 2005
2005	Pacific Lamprey and Western Brook Lamprey listed as "at risk" in Oregon	ODFW 2006
2007	U.S. Fish and Wildlife Service commences Pacific Lamprey Conservation Initiative (PLCI)	Luzier et al. 2009, 2011; USFWS 2012
2008	U.S. Army Corps of Engineers' (USACE) Adult Lamprey Passage Plan	USACE 2008
2008[b]	CRITFC Lamprey Summit II; Draft Tribal Pacific Lamprey Restoration Plan	
2011	Pacific Brook Lamprey from Clackamas River verified as unique species	Reid et al. 2011
2011	Pacific Lamprey Assessment and Template for Conservation Measures	Luzier et al. 2011
2011	Tribal Pacific Lamprey Restoration Plan for the Columbia River Basin	CRITFC 2011
2012	U.S. Bureau of Reclamation assessment of projects	USBR 2012
2012	Lamprey Summit III; Pacific Lamprey Conservation Agreement established	USFWS 2012
2013	Western River Lamprey listed as a sensitive species in Oregon	ODFW 2016; OCS 2017
2013	U.S. Fish and Wildlife Service's regional implementation (conservation) plans initiated	
2014	USACE Adult Lamprey Passage Plan, revised	USACE 2014
2014	Northwest Power and Conservation Council's Fish & Wildlife Program added guidance for Pacific Lamprey	NWPCC 2014
2015[c]	Regional implementation plans for Pacific Lamprey management units	USFWS 2015
2016	ODFW creates a Statewide Lamprey Coordinator position to lead the agency's lamprey conservation efforts	
2017	Lamprey Summit IV	
2018	Lamprey Master Supplementation plan approved through Independent Science Review Panel and NWPCC	CRITFC et al. 2018
2018	Bonneville Power Administration and NWPCC establish funding for Pacific Lamprey in the Columbia Basin	

[a] Established by the NWPCC to coordinate lamprey projects through the Bonneville Power Administration. This group now focuses on issues within and outside of the Columbia River basin.

[b] Lamprey Summits were led by the Columbia River Inter-Tribal Fish Commission (CRITFC) to celebrate Pacific Lamprey and to provide opportunities for CRITFC tribes to meet with agencies to plan restoration of this species. Lamprey Summit II culminated in the tribal restoration plan (CRITFC 2011), Lamprey Summit III culminated in the Pacific Lamprey Conservation Agreement (USFWS 2012), and Lamprey Summit IV culminated in re-signing of this agreement.

[c] Includes the development of prioritized conservation actions through the Pacific Lamprey Conservation Agreement (USFWS 2012).

Chapter 2: Biology and management units

This chapter provides an overview of lamprey biology and concludes with a presentation of management units. Knowledge of lamprey biology forms the foundation of the CPL. A more thorough review of their diversity and ecology is presented in Appendix 3.

Lampreys are primitive, eel-like fishes. Instead of bones, lamprey bodies are supported by cartilage. Lampreys have no jaws, paired fins, or a swim bladder. They have a single nostril, seven branchial pores or gill pouches on either side of their head, two dorsal fins, and a caudal fin.

The four species of lampreys covered in the CPL express a wide range of life histories, life styles, feeding strategies, and upstream migration distances in freshwater (Table 2.1). Larvae range in length from < 1 – 7 in (Table 2.1). Transformed individuals of the parasitic lamprey species, Pacific Lamprey and Western River Lamprey, have eyes and mouths that are relatively large compared with their body sizes. The sucker mouth (also known as oral disc) of these parasitic lampreys is an adaptation for feeding on prey in seawater, including teeth and a rasping tongue (Figure 2.1; Manzon et al. 2015).

Figure 2.1. Adult Western River Lamprey captured from the Yaquina River, shown attached by its oral disc to the side of a plastic tank. Image from Trevan Cornwell, ODFW.

Table 2.1. Body sizes, migratory life history (A = anadromous; R = resident), maximum upstream migration distances, and adult feeding behavior of lampreys covered in the CPL. References: Vladykov (1973); Moyle (2002); Orlov et al. (2008); IDFW (2011); Reid et al. (2011); Renaud (2011); McIlraith et al. (2015) Moser et al. (2015b); Potter et al. (2015), and Weitkamp et al. (2015).

Common name	Max larval body size (in)	Adult body size (in)	Life style	Max upstream (mi)	Juvenile feeding mode
Pacific Lamprey	8	13 – 33	A	Up to 746+	Parasitic (blood)
Western River Lamprey	8	4 – 12	A	Unknown	Predator (tissue)
Western Brook Lamprey	8	3 – 7	R	Unknown	Non-feeding
Pacific Brook Lamprey	8	4 – 7	R	Unknown	Non-feeding

LIFE HISTORY

Pacific Lamprey (Figure 2.2) and Western River Lamprey (Figure 2.1) are the largest of the four lampreys covered in the CPL, and they are anadromous and parasitic. Western Brook Lamprey

(Figure 2.3) and Pacific Brook Lamprey are the smallest lampreys covered in the CPL, and these species live their entire lives in freshwater and do not feed as adults (Table 2.1).

All lampreys are nocturnal (Moser et al. 2015a, b). During the day, larvae tend to stay in burrows at the bottom of the streambed and upstream migrating adults tend to conceal themselves with some form of cover (Clemens et al. 2012a). Larvae and juveniles enter the water column for downstream migration and adults migrate upstream at night (Goodman et al. 2015; Moser et al. 2015a, b).

Similarities and differences exist among the life stages of anadromous and resident lampreys. All lampreys have larval and adult stages[2]. A key difference is that anadromous lampreys have a juvenile life stage, whereas resident lampreys do not. Transformed, anadromous lampreys are sexually immature juveniles, whereas transformed, resident lampreys sexually mature soon after metamorphosis (Appendix 2; Docker 2009; Moser et al. 2015b; Potter et al. 2015). Juvenile lampreys grow as they feed on prey in the estuary or ocean before returning to fresh water to spawn. Anadromous lampreys returning to freshwater to spawn are “adults” (Appendix 2). All lampreys die after spawning (Johnson et al. 2015). The life stages are described below.

Figure 2.2. Adult Pacific Lamprey collected from Willamette Falls during one collection date (range in body length: 21 – 27 in). Image from Benjamin Clemens, ODFW.

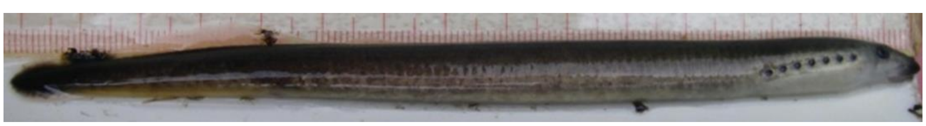

Figure 2.3. Adult Western Brook Lamprey (> 6 in body length) from the Willamette Basin. Image from Benjamin Clemens, ODFW.

[2] *See Appendix 2 for recommended life stage terminology.*

Larval

Larval lamprey (~0.3 in) dislodge from interstitial spaces between gravel at about three to four weeks post-egg fertilization (Meeuwig et al. 2005; Renaud 2011; Lampman et al. 2016). They disperse downstream until suitable burrowing habitat is found or spring flows subside (Dawson et al. 2015). As eyeless larvae, lampreys reside in burrows in low flow (depositional) areas of streams, within soft substrates, primarily composed of silt, sand, and organic matter (Dawson et al. 2015). Larvae occur in lower portions of large rivers including the deltas of tributary river mouths (Jolley et al. 2012; Harris and Jolley 2016), in large river channels (Jolley et al. 2012), wadable streams (Torgersen and Close 2004; Renaud 2011), and side channels (Schultz et al. 2014).

The larval life stage for lampreys (Figure 2.4) generally lasts for 3 –8 yrs (Dawson et al. 2015; Moser et al. 2015a), with recent data indicating that some larval Pacific Lamprey are ~10 yrs old (Jon Hess, Columbia River Inter-Tribal Fish Commission, unpubl. data). Within their burrows, larvae orient with their funnel-shaped mouths towards the substrate/water interface, where they filter feed on fine particulate matter (detritus, diatoms; Dawson et al. 2015). Larval lamprey may exit the substrate at night to move upstream or downstream (Quintella et al. 2005; Goodman et al. 2015; Moser et al. 2015a). The extent of daily movements by individual lampreys in Oregon is unknown, but may be like other species of lampreys. For example, larval Sea Lamprey in Europe were documented moving 1 – 90 ft over a two-month period (Quintella et al. 2005). Larval lamprey may emigrate throughout the year (Hayes et al. 2013; Moser et al. 2015a). Larval lamprey passively distribute downstream at night and this can be facilitated with high river flows. They may be scoured from the substrate at very high flows (Moser et al. 2015a).

Figure 2.4. A. Larval lamprey (< 1in body length). To envision the size and shape of these fish, consider that lamprey biologists often refer to this tiny lamprey as “eyelashes” or “pine needles”.
B. Larval Pacific Lamprey (3.5 in long). The size of each fish is shown at the same scale. Images from Benjamin Clemens, ODFW.

Transformation

All larval lampreys undergo metamorphosis (herein, “transformation”) during which their anatomy, physiology, and behavior change significantly. Lampreys transform as a result of external environmental cues and internal physiological cues related to growth and internal fat content. Metamorphosing lampreys stop feeding, shrink in body size, and undergo color changes (Manzon et al. 2015). They develop eyes and their mouths change from a funnel-shaped opening for filter feeding to a sucker disc. Transformation tends to occur late in the year (Table 2.2) and the timing varies by geographic location. The sex of lampreys changes during transformation from sexually indistinct (pre-transformation) to either distinctly male or female post transformation (Hardisty 1971; Clemens et al. 2012c).

Both parasitic and non-parasitic lampreys develop teeth. However, parasitic lampreys develop more and sharper teeth (Renaud 2011; Manzon et al. 2015). Upon transformation, Pacific Lamprey and Western River Lamprey develop proportionally large eyes, well-developed oral discs with teeth adapted to attach to prey, and a tongue piston adapted to rasping into prey flesh for feeding. At this point, these species are juveniles.

Upon transformation, resident brook lampreys (Western Brook Lamprey and Pacific Brook Lamprey) have eyes that are small relative to body size (Figure 2.3). Brook lampreys do not feed after transformation. Unlike parasitic lampreys, newly transformed brook lampreys are near sexual maturation, and they can be called "adults" (Appendix 2). These adults may stay burrowed in the substrate of the streambed until spring when they emerge and migrate to spawning grounds (Pletcher 1963).

Table 2.2. General life history traits of lampreys. Return and spawning seasons may occur earlier at lower latitudes, and depend upon the total upstream migration distance (Clemens et al. 2010). NA = not applicable. References: Ralph Lampman (Yakama Nation; pers. comm.); Scott and Crossman (1973); Kan (1975); Beamish (1980); Beamish and Youson (1987); Beamish and Levings (1991); Whyte et al. (1993); van de Wetering (1999); Meeuwig et al. (2005); McGree et al. (2008); Brumo et al. (2009); Clemens et al. (2010, 2013, and 2017a); Renaud (2011); Dawson et al. (2015); Moser et al. (2015a, b); Jolley et al. (2016).

	Pacific Lamprey	Western River Lamprey	Western Brook Lamprey	Pacific Brook Lamprey
Transformation [a]	Jul – Dec	Jul – Apr	Aug – Nov	Autumn (Oct)
Juvenile outmigration	Autumn – Spring	Apr – Jul [c]	NA	NA
Ocean rearing	≤ 3.5 yrs	< 1 yr	NA	NA
Return timing	Mar – Sep	Sep – late winter	NA	NA
Upstream migration	0 – 2+ yrs	Few mos	Few mos	Few mos
Age at maturity [b]	4 – 13 yrs	5 – 9 yrs	5 – 7 yrs	*Unknown*
Spawning	Mar – Aug	Apr – Jun	Apr – Jul	Apr – Aug
Fecundity (no. eggs)	98,000-238,400	11,398-37,288	1,100-3,700	*Unknown*

[a] This information is based on published studies, and little research has been conducted on Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey relative to Pacific Lamprey. Transformation dates may not be significantly different among species, and may be more a function of regional differences.

[b] These age estimates are variable and uncertain, particularly for Western Brook Lamprey.

[c] Of the year following transformation in coastal rivers.

Juvenile

The term, "juvenile", applies to parasitic lampreys (Pacific Lamprey and Western River Lamprey; Appendix 2). Recently transformed, parasitic lamprey (Figure 2.5) and those that have been feeding in seawater are "juveniles". By contrast lampreys migrating upstream to spawning grounds are adults (Figures 2.1 – 2.3; Appendix 2). Juveniles tend to be found on or near the surface of the substrate, and can be associated with gravel (Beamish 1980). This may facilitate their downstream movement towards the sea. Downstream migrations of juvenile lampreys are thought to be passive, although some directed swimming movements may position them into current (Moser et al. 2015a). Most downstream migration occurs during the nighttime (Liedtke et al. 2019). Juvenile lampreys undergo downstream migrations during high water events from autumn through spring (Table 2.2; Dawson et al. 2015; Goodman et al. 2015). The duration of ocean rearing differs between anadromous lampreys, with the larger Pacific Lamprey having the potential to rear in seawater for a longer time period than Western River Lamprey (Table 2.2).

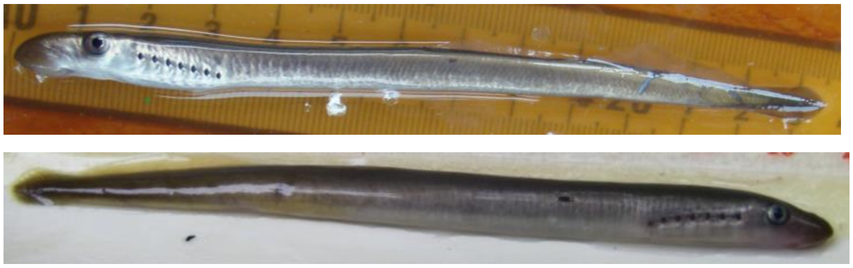

Figure 2.5. Juvenile Western River Lamprey (top image; 5 in body length) and Pacific Lamprey (bottom image; 4 in body length). Image credits, top to bottom: NOAA Fisheries and Benjamin Clemens (ODFW).

Adult

The return season of Pacific Lamprey and Western River Lamprey differs, appearing to be longer and more flexible for Pacific Lamprey than Western River Lamprey (Table 2.2). However, little research has been conducted on Western River Lamprey. Anadromous, parasitic lampreys grow large from feeding on prey, and they have greater fecundity (numbers of eggs) than the resident brook lampreys (Table 2.2). Adult Pacific Lamprey have been found in the Columbia River estuary January – May (Weitkamp et al. 2015), which along with other information (Table 2.2) suggests a return season of March – September. Because the duration of the return migration for Pacific Lamprey can range from a few months to a few years (Table 2.2), adult lamprey may exist within a particular river throughout the year. Language has been suggested to categorize the upstream migration for adults, including: 1) an initial migration, 2) pre-spawning holding, and 3) final migration/spawning (Robinson and Bayer 2005; Clemens et al. 2010, 2012a, and b).

Migratory pheromones

Lampreys communicate with each other by releasing and detecting pheromones (biochemical messages detected by smell) and they can be attracted to pheromones of other lamprey species (Fine et al. 2004; Moser et al. 2015b). Migratory pheromones are released by larval lamprey and attract adult lamprey to suitable spawning and rearing habitats (Fine et al. 2004; Yun et al. 2011; Moser et al. 2015b).

Migratory pheromones from larval Pacific Lamprey may not always be necessary to cue this species to rivers for spawning. A growing body of evidence indicates that Pacific Lamprey recolonize habitats in various river basins that were formerly blocked by dams, rock slides or volcanic eruptions (Maitland et al. 2015; Clemens et al. 2017a; Moser and Paradis 2017; Jolley et al. 2017). It is unknown if these recolonizing Pacific Lamprey were attracted to the migratory pheromones of resident brook lampreys in those rivers or whether Pacific Lamprey cued their migrations into those rivers to spawn by other means.

Lampreys also respond to alarm cues and predator odors and may be deterred from migration when dead lamprey or predators are present. However, responses vary and require further study (Imre et al. 2014; Porter et al. 2017).

Spawning

Spawning occurs in the spring (Table 2.2) and depends upon external environmental cues and internal physiological cues (Sower 2003; Clemens et al. 2010). In coastal Oregon, relatively low flows and warm water temperatures were likely associated with earlier spawning, whereas relatively high river flows and cool water temperatures are associated with the slowing or even cessation of spawning (Brumo et al. 2009; also see Appendix 3). All lampreys die after spawning (Renaud 2011; Johnson et al. 2015). Depending on the species, lampreys die within hours to weeks of spawning (Pletcher 1963; Beamish 1980; Renaud 2011).

Male Pacific Lamprey may arrive at spawning grounds earlier than females (Scott and Crossman 1973; Clemens et al. 2010). Male Pacific Lamprey may release pheromones that attract females to nests (redds; Robinson et al. 2009; Yun et al. 2014; Moser et al. 2015b). Pacific Lamprey excavate redds by attaching their oral discs to rocks and moving them to the perimeter of a circular depression that becomes the redd (Stone 2006; Gunckel et al. 2009). Pacific Lamprey spawn in groups of two to four individuals in these gravel-lined redds (Stone 2006; Starcevich et al. 2014; Johnson et al. 2015), although recent information indicates that up to eight individuals may spawn together in a redd comprised of a pile of rocks (e.g., in the Eel Lake Basin, Lakeside, Oregon; Richard Litts, Tenmile Lakes Basin Partnership, unpubl. obs.). Individual males may spawn with multiple females in multiple locations (Scott and Crossman 1973; Starcevich et al. 2014). The fecundity of Pacific Lamprey is much greater than the other lampreys (Table 2.2).

Little information is available on the spawning behavior of Western River Lamprey. The numbers of individuals involved in spawning is unknown, but given their body size and inter-relatedness to Western Brook Lamprey, spawning may include up to several individuals (Johnson et al. 2015). Western River Lamprey and Western Brook Lamprey can spawn together and produce offspring (Beamish and Neville 1992; Docker et al. 1999; Docker 2009).

Redd excavation and spawning by Western Brook Lamprey is similar to Pacific Lamprey, albeit with more lamprey involved, in shallower water, and using smaller substrate than Pacific Lamprey (Appendix 3). Western Brook Lamprey may rely on their tails more than their mouths or heads to excavate gravel from a redd (Scott and Crossman 1973). Western Brook Lamprey spawn within groups of up to 12 individuals (Scott and Crossman 1973; Stone 2006). Information is currently unavailable on the spawning characteristics of Pacific Brook Lamprey. However, given their inter-relatedness with Western Brook Lamprey, the spawning characteristics may be similar.

DISTRIBUTION

All lampreys in the CPL overlap in their distributions (Figures 2.6 – 2.9). Pacific Lamprey are the most widely distributed lamprey along the West Coast of North America. The distribution of Pacific Lamprey ranges from Baja, Mexico north to the Bering and Chukchi seas off Alaska (Renaud 2008). Pacific Lamprey are broadly distributed in Oregon (Figure 2.6) and are found primarily in large, low elevation streams (Gunckel et al. 2009).

Western River Lamprey occupy watersheds with large estuaries in in the Salish Sea, Puget Sound, Columbia, and Sacramento rivers (Potter et al. 2015; Stewart Reid, Western Fishes, pers. comm. 2016). Their distribution is not fully understood. Western River Lamprey have been collected at Bonneville Dam (Vladykov and Follett 1958). A single juvenile Western River Lamprey was found at each of two previously undocumented locations, including within the Siletz River (Docker 2009), and in the mid-Columbia River, entering John Day Dam from upstream, 216 miles from the ocean (Jolley et al. 2016; Figure 2.7). Finally, Western River Lamprey has been found more recently in the Yakima River in Washington (Ralph Lampman, Yakama Nation, pers. comm.).

The distribution of Western Brook Lamprey ranges from California (Moyle 2002) north to Alaska (Potter et al. 2015). Western Brook Lamprey is distributed throughout Coastal Oregon (Boguski et al. 2012) and into the Willamette and mid-Columbia Figure 2.8). This lamprey is found primarily in higher elevation sites, with relative small active channel widths, including headwater streams (Gunckel et al. 2009). However, Western Brook Lamprey can also be found in mainstem rivers at lower elevations (e.g., the lower Yakima River and the South Umpqua River near the city of Canyonville; Ralph Lampman, Yakama Nation pers. comm.; Kelly Coates, Cow Creek Tribe of Umpqua Band of Indians, pers. comm.). The distribution of Pacific Brook Lamprey is less well understood, but it includes the Lower Columbia and Willamette (Reid et al. 2011). Distribution records occur elsewhere in coastal Oregon (Figure 2.9).

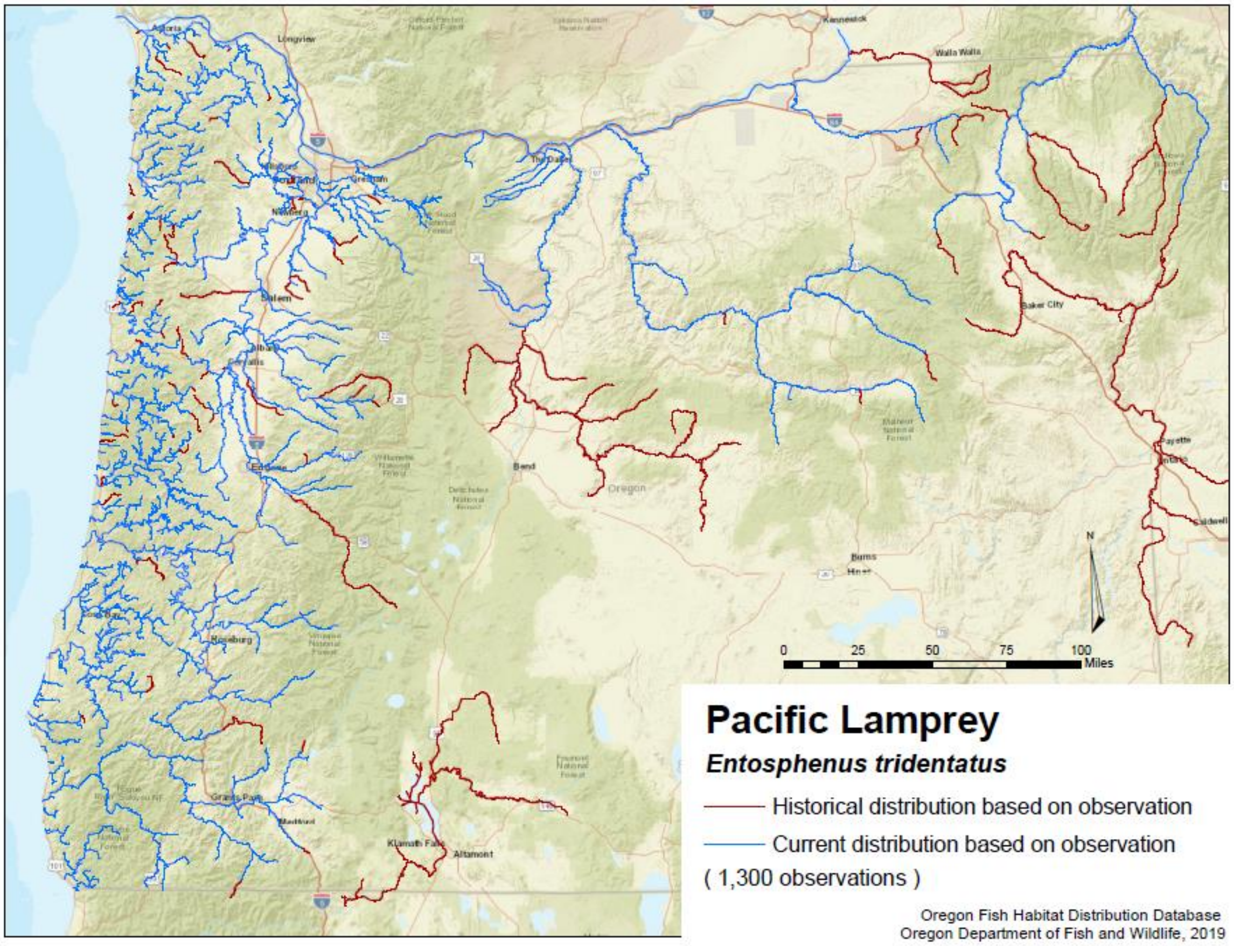

Figure 2.6. Known distribution of Pacific Lamprey in Oregon.

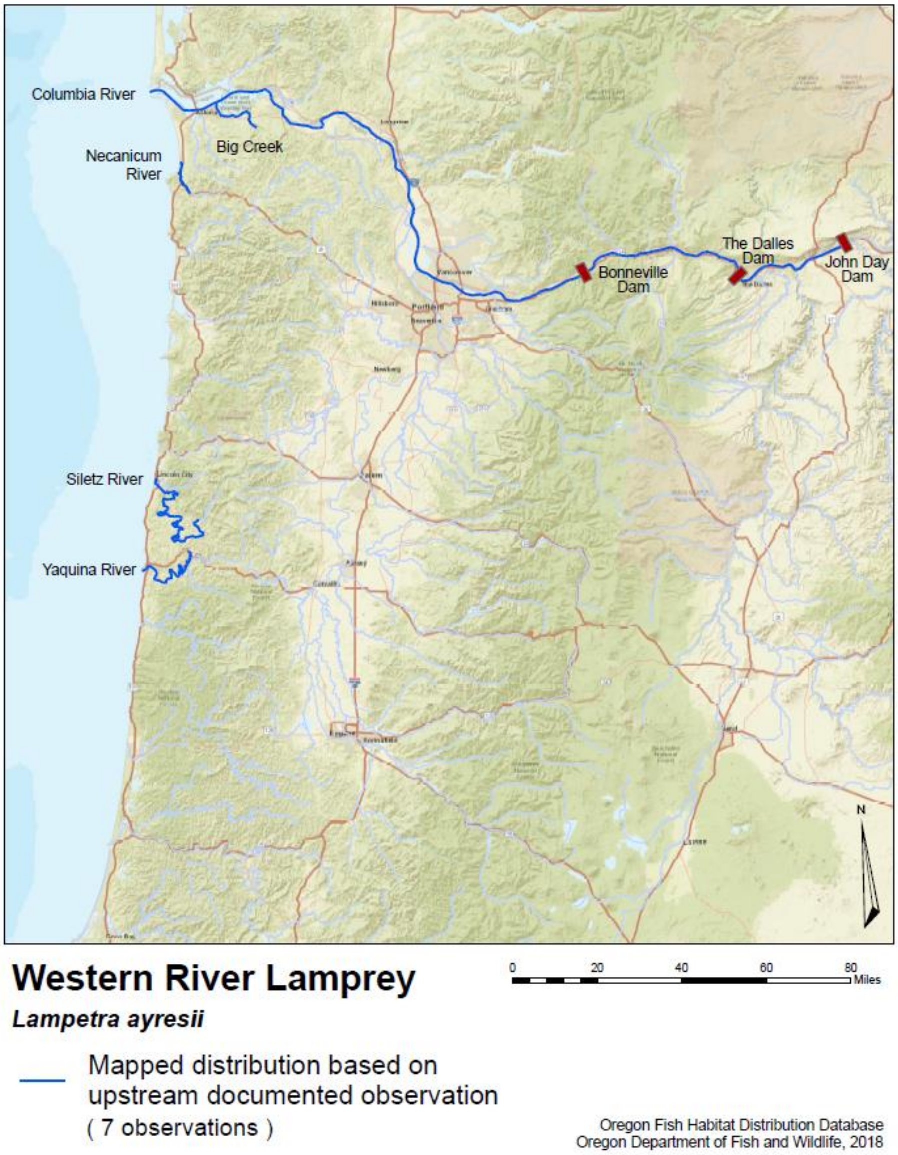

Figure 2.7. Documented distribution of Western River Lamprey in Oregon.

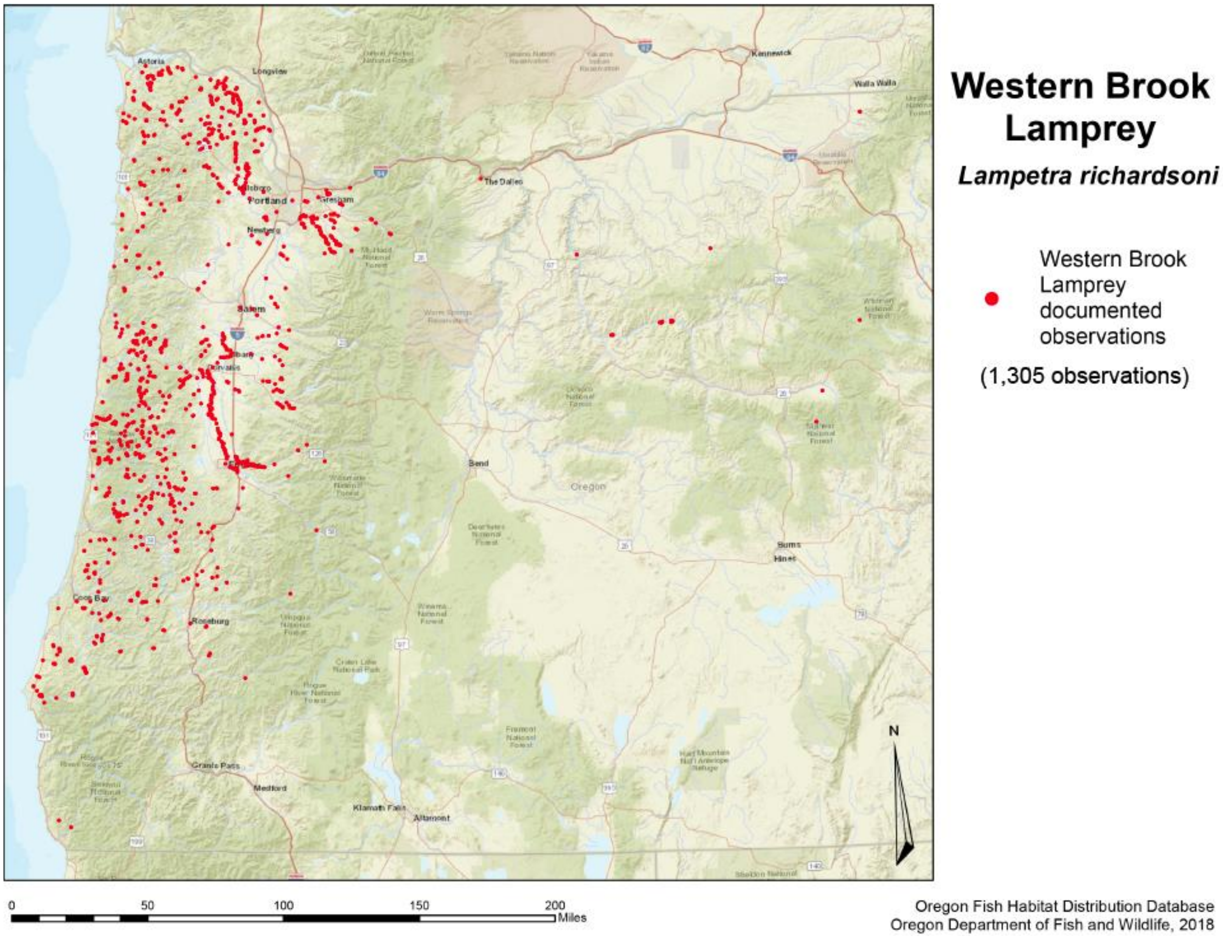

Figure 2.8. Observation points for Western Brook Lamprey in Oregon.

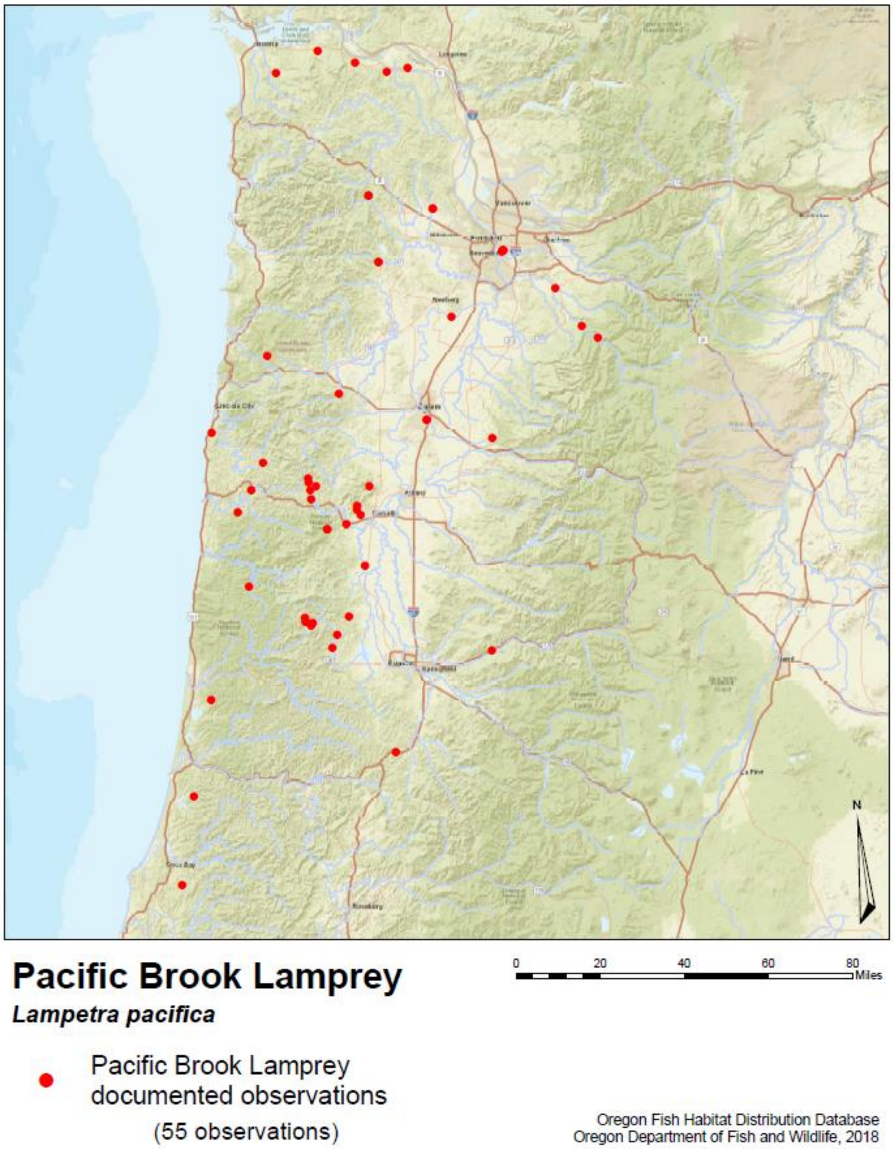

Figure 2.9. Observation points for putative specimens of Pacific Brook Lamprey (identifications based on morphology and subject to verification) in Oregon. Beyond the initial species description of Pacific Brook Lamprey from the Clackamas River (Vladykov 1973) and its recent re-description (Reid et al. 2011), little work has been done on this species. However, they have been collected from 55 locations in Oregon, within the northern coast of Oregon and the Willamette Basin.

MANAGEMENT UNITS

The CPL includes two scales: 1) population stratum and 2) Species Management Unit (SMU). Biological status and management actions were determined at the stratum scale. Seven strata exist for the lampreys covered in this plan (Table 2.3 and Figure 2.10). The conservation unit at which state listing (ESA and sensitive species status) is determined is the SMU scale. The SMU for all lampreys is the State of Oregon.

Genetic structuring of lampreys occurs at regional levels that overlap with strata in Oregon (Appendix 3). Unlike adult salmon and steelhead, adult Pacific Lamprey do not home to the same streams from which they were born (reviewed in Appendix 3). Information on homing for other lampreys is unclear (Appendix 3). Detailed monitoring for lampreys is lacking across many watersheds. Management and research of lampreys at the stratum level is where improvements in status and information may be most easily attained. A comparison between ODFW's strata and the USFWS's Regional Management Units for Pacific Lamprey is shown in Table A4.1 of Appendix 4.

Table 2.3. Distribution of lampreys relative to population strata. NA = not applicable at this time because the current, documented or likely distribution does not include these population strata.

		Pacific Lamprey	Western River Lamprey	Western Brook Lamprey	Pacific Brook Lamprey
Population strata	Rogue/South Coast	X	NA	X	NA
	Coastal	X	X	X	NA
	Lower Columbia	X	X	X	X
	Willamette	X	NA	X	X
	Mid Columbia	X	X	X	NA
	Lower Snake	X	NA	NA	NA
	Upper Snake	Extirpated	NA	NA	NA

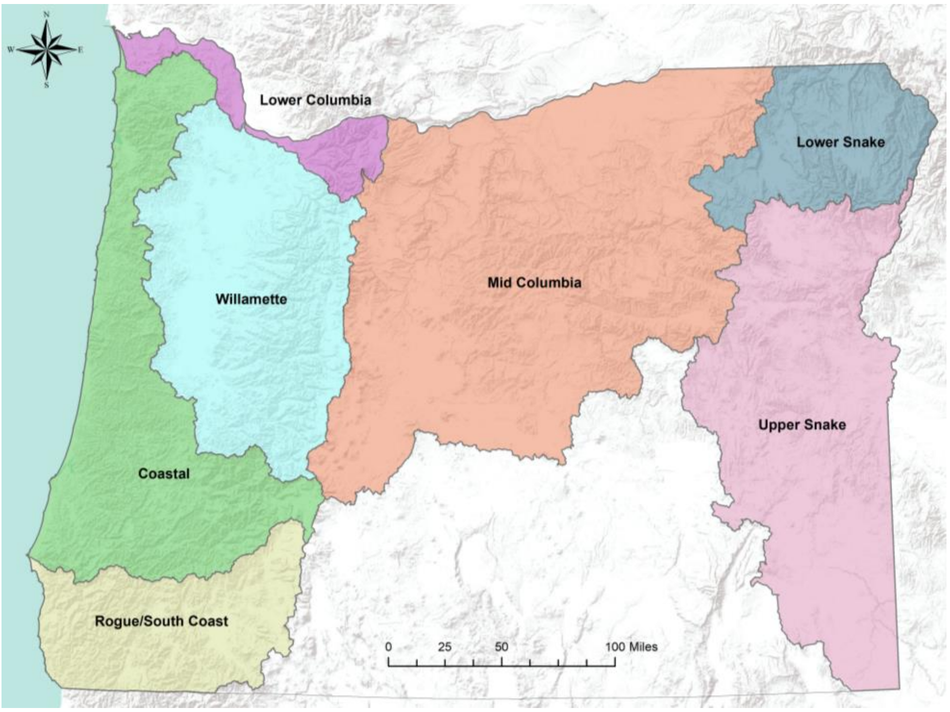

Figure 2.10. Map showing the seven population strata used for the lampreys in this conservation plan. These seven strata form the basis of a single, statewide Species Management Unit for each species.

Chapter 3: Current biological status

This chapter presents analyses of measurable criteria and status assessments for Pacific Lamprey. Sufficient data existed to assess three measurable criteria, including distribution (measurable criterion 6a, Table 3.1), adult abundance trend (measurable criterion 6b, Table 3.1), and connectivity (measurable criterion 6d, Table 3.1)[3]. Lack of data precluded assessments of measurable criteria and status for Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey.

Species distribution models (SDMs) were used to predict the probability of occurrence (distribution) for Pacific Lamprey. The SDMs were informed by lamprey presence/absence data and environmental data that might predict lamprey occurrence. This was done where sufficient data existed in Western Oregon (Table 3.1). General abundance trends for Pacific Lamprey were assessed (Table 3.1). To ascertain abundance trends for adult Pacific Lamprey, data from dam counts, spawning ground surveys, and mark/recapture estimates were analyzed using simple statistical correlations and professional opinion of graphical trends. Connectivity was assessed (Table 3.1) by identifying and enumerating key artificial obstructions.

Table 3.1. Measurable criteria used to assess current status, per the Native Fish Conservation Policy (OAR 635-007-0502 through 0509; ODFW 2003). Approaches address the criterion for where data exist for Pacific Lamprey (PL). PS = population strata: RSC = Rogue/South Coast; CST = Coastal; LC = Lower Columbia; WI = Willamette; MC = Mid Columbia; LS = Lower Snake, and US = Upper Snake.

Measurable criteria	Approaches	Species	Data Sources (and PS)
6a. Distribution of populations within unit	Species distribution models	PL	Various (RSC, CST, LC, WI)
6b. Adult fish abundance for constituent populations	Adult abundance trends	PL	Adult dam counts (RSC, CST, LC, WI, MC, LS, US) Extrapolations of conservative abundance indices from redd surveys (CST, LC, WI) Abundance estimates (LC, WI, MC)
6c. Within and among population diversity	Not currently possible to assess	–	Currently none
6d. Population connectivity	Enumerate major artificial obstructions to anadromy	PL	Barrier database (RSC, CST, LC, WI, MC, LS, US)
6e. Survival rate to each critical life stage	Not currently possible to assess	–	Currently none
6f. Standardized rate of population growth for constituent natural populations	Not currently possible to assess	–	Currently none
6g. Forecast likelihood of species management unit persistence in the near and long terms	Not currently possible to assess	–	Currently none

[3] *At least five main challenges exist for monitoring lampreys. These challenges preclude traditional assessments of population status: 1) Pacific Lamprey do not home to natal streams, consequently population structure within watersheds cannot (yet) be identified, 2) long term, accurate count data at dams is lacking, 3) standardized biological surveys are lacking, 4) recruits per spawner data are not available, and 5) the ages of individuals cannot (yet) be reliably estimated (USFWS 2004; Moser et al. 2007; Clemens et al. 2017a).*

ANALYSES TO ASSESS MEASURABLE CRITERIA

Distribution

To assess distribution of Pacific Lamprey (measurable criterion 6a; Table 3.1), the probability of occurrence was modeled for the Rogue/South Coast, Coastal, Lower Columbia, and Willamette population strata using logistic regression (Figure 3.1). A lack of distribution data for Pacific Lamprey in Eastern Oregon precluded development of SDMs in the Mid Columbia, Lower Snake, and Upper Snake population strata. Candidate models were developed using environmental variables hypothesized to influence the distribution of Pacific lamprey. Three types of models were considered during model development: 1) simple, temperature and flow only models, 2) the full, global model excluding interactions and polynomial relationships, and 3) models containing both polynomial terms and/or interactions. Multicollinearity was evaluated among predictor variables and two different statistics were used to exclude and/or retain variables. Logistic regression models were evaluated using Akaike Information Criterion (AIC) values and Akaike weights (Burnham and Anderson 2002). Model validation was conducted for the candidate models and the null model. Appendix 5 provides a more thorough description of the methods.

The SDMs modeled suitable (rather than available) habitat for lampreys, so these models did not control for artificial obstructions that could prohibit upstream distribution. Data for occurrence and variables that could predict occurrence were used to develop SDMs. Details on SDMs are presented in Appendix 5. The main results are reported in Table 3.2 and the following bullets:

- the probability of occurrence of Pacific Lamprey is generally highest in the Coastal stratum
- the probability of occurrence of Pacific Lamprey declines in the eastern, interior-most portions of all strata examined (in association with the presence of major dams), and in other portions of the Rogue/South Coast and Coastal strata (Figure 3.1).

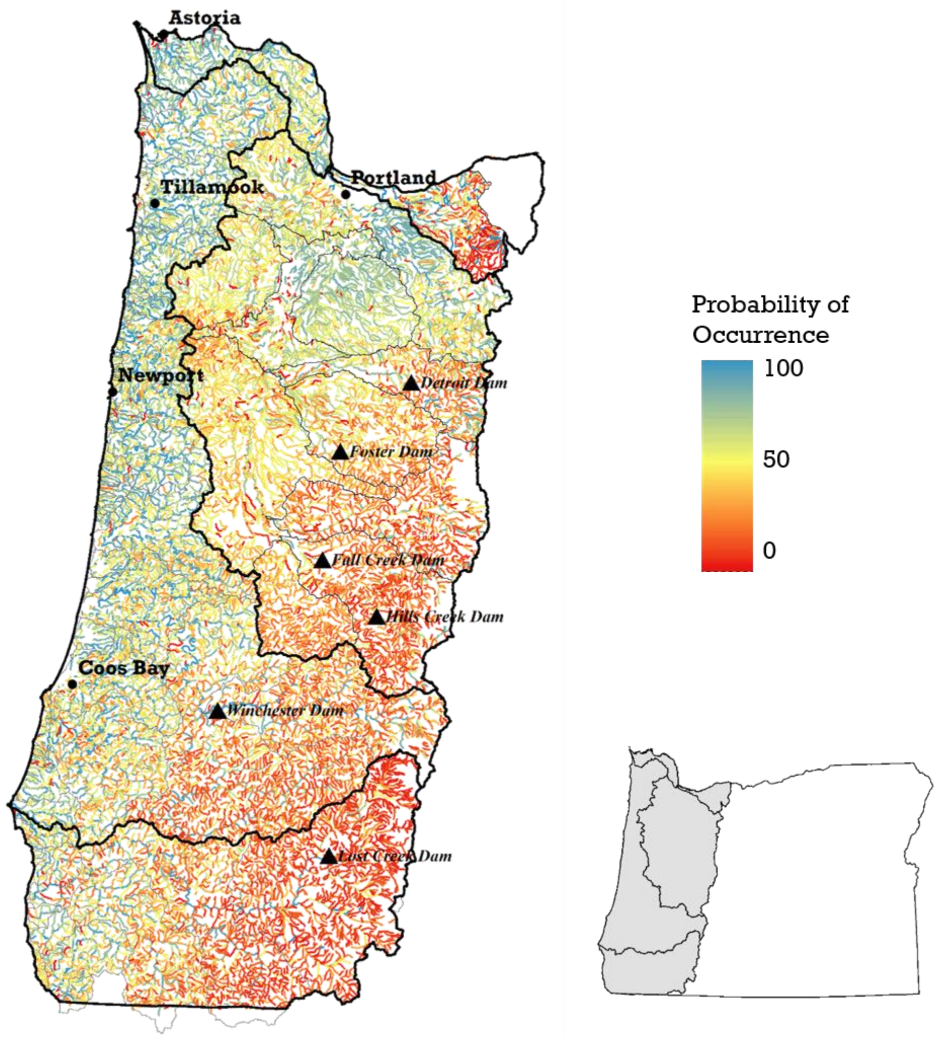

Figure 3.1. Probability of occurrence of Pacific Lamprey across population strata in Western Oregon, including the Rogue/South Coast, Coastal, Lower Columbia, and Willamette strata. The probability of occurrence is based on the best distribution model for baseline (1993 – 2011). The color ramp represents the probability of occurrence, with red being the lowest and blue the highest. Oregon inset shows the state boundary with the four PS included in this analysis.

Table 3.2. Probabilities of occurrence (standard deviation in parentheses) for Pacific Lamprey. The number of surveys are shown in Table A5.3 as "N per strata"). A dash (–) = Data/information not assessed.

Population stratum	Average probability of occurrence
Rogue/South Coast	0.239 (0.265)
Coastal	0.404 (0.279)
Lower Columbia	0.289 (0.276)
Willamette	0.255 (0.172)
Mid Columbia	–
Lower Snake	–
Upper Snake	–

Adult abundance trend (mid 1900s – present)

Trends in abundance of adult Pacific Lamprey were assessed within individual population strata (measurable criterion 6b; Table 3.1). Specifically, data from dam counts, spawning ground surveys, and mark/recapture estimates were analyzed using simple statistical correlations and professional opinion of graphical trends. Details on abundance trends are presented in Appendix 6. The main results are reported in Table 3.3 and the following bullets:

- the relative abundance of adult Pacific Lamprey has declined along the coast of Oregon and into the Columbia River Basin since the mid-1900s
- more recently (i.e., over the last decade) the relative abundance of adult Pacific Lamprey has increased in parts of the Coastal, Willamette, and Mid Columbia strata; however, these increases are a small proportion of the relative abundance of the mid-1900s
- modest increases in abundance of adult Pacific Lamprey in recent years relative to historical information (late 1800s – early 1900s) and the cyclical nature of these trends do not unequivocally suggest decreasing, stable, or increasing trends in abundance across five strata: the Rogue/South Coast, Coastal, Lower Columbia, Willamette, and Mid Columbia (i.e., the trends for these are "unknown")
- with some exceptions, dam counts and spawning ground surveys generally show similar trends in relative abundance across time
- correlations between the Coastal stratum and the mainstem Columbia River suggest similar cyclical trends in abundance (increases and subsequent decreases) of adult Pacific Lamprey over time, which could be the result of ocean conditions acting on one interconnected population (Appendix 3).
- given the low numbers of adult Pacific Lamprey passing Lower Granite Dam that could select tributaries within the Lower Snake stratum and the absence of Pacific Lamprey in the Upper Snake stratum, the trends for these two strata are noted to have a "decreasing" trend, and absence, respectively.

Table 3.3. Trends in the abundance of adult Pacific Lamprey, by population stratum (PS). Years over which these data occur vary by strata and data sources (see Tables A6.1 and A6.2). The "Adult abundance trend within PS" score is categorical, where "0.5" = unknown trend, and "0" = decreasing trend or absence of Pacific Lamprey. Also shown are the data sources (DC = dam counts; SGS = spawning ground surveys; M/R = mark/recapture estimates, and O = observational), and analyses.

Population stratum	Data sources	Analyses	Adult abundance trend within PS
Rogue/South Coast	DC	Statistical correlations, graphical trends	**0.50**
Coastal	DC, SGS	Statistical correlations, graphical trends	**0.50**
Lower Columbia	DC, SGS, M/R	Statistical correlations, graphical trends	**0.50**
Willamette	DC, SGS, M/R	Statistical correlations, graphical trends	**0.50**
Mid Columbia	DC, M/R	Statistical correlations, graphical trends	**0.50**
Lower Snake	DC	Graphical trends	**0** [a]
Upper Snake	O	Observation	**0**

[a] Based on few individual adults counted at Lower Granite Dam in the Lower Snake River (Figure A6.3 in Appendix 6).

Connectivity

Key artificial obstructions (i.e., large barriers on large rivers) that may disrupt anadromy for Pacific Lamprey were identified and enumerated to assess connectivity (measurable criterion 6d; Table 3.1). More interior strata are generally less connected. For example the Upper Snake has the most obstructions for Pacific Lamprey to encounter whereas the Coastal stratum has the fewest (Table 3.4). Details on connectivity are provided in Appendix 7.

Table 3.4. Tally of artificial obstructions (listed in Table A7.2) to anadromy, by population stratum. Artificial obstructions were identified on 5th order and larger streams (Appendix 7). "Connectivity score" is a category associated with the total number of obstructions: 1 = most connected (least dams); 0.75 = moderately connected; 0.5 = less connected and 0 = disconnected (most dams).

Population stratum	In population stratum	Downstream	Total (In population stratum + Downstream)	Connectivity score
Rogue/South Coast	5	0	5	**0.75**
Coastal	1	0	1	**1.00**
Lower Columbia	5	0	5	**0.75**
Willamette	16	0	16	**0.50**
Mid Columbia	29	1	30	**0.00**
Lower Snake	0	8	8	**0.75**
Upper Snake	27	8	35	**0.00**

ASSESSMENT OF CURRENT STATUS

Methods

Adjusted probabilities from the "Average probability of occurrence" (Table 3.2), the "Adult abundance trend within PS" column in Table 3.3, and "Connectivity score" column in Table 3.4 were copied to respective columns in Table 3.6. These three scores were used to calculate an overall population stratum score (Table 3.6), which corresponded with a ranking for current status (Table 3.7).

The population stratum score was calculated as an average of the "Average probability of occurrence", "Adult abundance trend within PS", and "Connectivity score", where adult abundance was given greater emphasis by weighting (multiplying by two)[4]:

[(2 X adult abundance trend) + Distribution + Connectivity] ÷ 4

The current status of the entire SMU (i.e., the state of Oregon) for each lamprey species was determined consistent with what is described in Table 7 of the *Coastal Multi-Species Conservation and Management Plan* (ODFW 2014)[5]. Briefly, the statuses of population strata were tabulated and considered with confidence in assessments and the level of immediate threats (Tables 3.8 – 3.9).

RESULTS AND DISCUSSION

In 1993, 2004, and 2013, Pacific Lamprey, Western River Lamprey and Western Brook Lamprey were respectively first listed as "sensitive" by the State of Oregon (Table 1.2). In addition, both Pacific Lamprey and Western Brook Lamprey were assessed for interim status in 2005, and categorized as "at risk" of extinction (ODFW 2006; Table 3.5). This chapter incorporates up-to-date information and in-depth analyses to provide a current status assessment for Pacific Lamprey. The current status of Pacific Lamprey ranges from "absent" to "prevalent" across the seven strata (Tables 3.6 – 3.7). The population strata statuses, assessment confidence, and threat levels resulted in a current overall status ranking of "sensitive" for each lamprey species SMU (Tables 3.8 – 3.9). This agrees with the 2016 state Species Sensitive List (SSL) for three of the lampreys (Table 3.5). Pacific Brook Lamprey was not included in the 2016 SSL, and it is now recommended for inclusion on that list as a sensitive species.

[4] *This criterion was given greater weight because of the obvious difference in abundance trends in population strata of Eastern relative to Western Oregon (Table 3.3; Appendix 6).*

[5] *Note that PS in the CPL, as the basic assessment unit, are equivalent to "Population" in the Coastal Multi-Species Conservation and Management Plan. Also, the SSL was updated after the Coastal Multi-Species Conservation and Management Plan was adopted and the "Sensitive-Vulnerable" designation was eliminated, so the CPL is only utilizing one "Sensitive" designation (Table 3.9).*

Table 3.5. Species Management Unit status of lampreys.

Species	2005 interim status	2016 state listing
Pacific Lamprey	At risk [a]	Sensitive [b]
Western River Lamprey	Not assessed	Sensitive [b]
Western Brook Lamprey	At risk [a]	Sensitive [b]
Pacific Brook Lamprey	Not assessed	Not listed

[a] ODFW (2006).

[b] Per OAR 635-100-0040 (ODFW 2016).

[c] Table 3.6

Table 3.6. Measurable criteria scores for Pacific Lamprey. Derivation of "Distribution", "Adult abundance trend", "Connectivity", and "PS score" values is described in the text. "Population stratum: Current status" categories are derived from Table 3.7.

	Measurable criteria				
Population stratum	**Distribution in PS**	**Adult abundance trend within PS**	**Connectivity score**	**PS score**	**Population stratum: Current status**
Rogue/South Coast	0.239	0.50	0.75	0.497	**Common**
Coastal	0.404	0.50	1.00	0.601	**Prevalent**
Lower Columbia	0.289	0.50	0.75	0.510	**Common**
Willamette	0.255	0.50	0.50	0.439	**Common**
Mid Columbia	–	0.50	0.00	0.250	**Limited**
Lower Snake	–	0.00	0.75	0.188	**Rare**
Upper Snake	–	0.00	0.00	0.000	**Absent**

Table 3.7. Population stratum (PS) score groupings and associated current status categories. Groupings are based on logical discretization consistent with best professional judgement.

PL PS score	Current status	Status description
≥ 0.600	**Prevalent**	Widely distributed, abundant, productive or diverse populations throughout entire assessment area
0.400 – 0.599	**Common**	Readily found, but not widely distributed, abundant, productive or diverse throughout entire assessment area
0.200 – 0.399	**Limited**	Reduced distribution, abundance, productivity or diversity throughout assessment area
0.100 – 0.199	**Rare**	Scarce within assessment area
< 0.100	**Absent**	Extirpated within assessment area

Table 3.8. Summary of viability results, confidence, and current overall status of the entire SMU.

	Pacific Lamprey	Western River Lamprey	Western Brook Lamprey	Pacific Brook Lamprey
Viable population strata [a]	4 of 7	Unknown	Unknown	Unknown
Population strata lacking information [b]	All (7 of 7)	All (3 of 3)	All (5 of 5)	All (2 of 2)
Level of immediate threats to future viability	Unknown	Unknown	Unknown	Unknown
Assessment confidence of population strata	Varies	Not applicable	Not applicable	Not applicable
Current overall SMU status	Sensitive	Sensitive	Sensitive	Sensitive

[a] Where “viable” = the number of population strata with a current status ranking of “Common” or “Prevalent”, which is a conservative estimate of viability (per Table 3.6).

[b] See Table 3.1.

Table 3.9. Definitions for Species Management Unit scores (adapted from ODFW 2014).

Current status	Status description
Strong	Widely distributed, have little if any viability concerns across populations, high confidence in the status assessment, and a lower level of immediate threats that may affect viability in the future. The management approach for these SMUs allows for providing societal benefits and fisheries in a manner consistent with long-term viability.
Strong-Guarded	Widely distributed, have little if any viability concerns across populations and a lower level of immediate threats that may affect viability in the future. However, either a lack of robust data relative to all VSP parameters or conflicting indications of viability warrant a cautious management approach when providing societal benefits and fisheries, especially with respect to potential threats and limiting factors.
Sensitive	Have little if any viability concerns across populations but are naturally limited in their range within the planning area, have a moderate level of immediate threats that may affect viability in the future, and/or viability status is unknown. Assessment confidence for these SMUs varies. A cautious management approach when providing societal benefits and fisheries, especially with respect to potential threats and limiting factors is warranted. Additionally, pro-active management of existing threats and limiting factors is warranted.
Threatened	Are not considered viable into the future, although individual populations may be viable and many may be able to persist in the near term, especially with pro-active management of threats and limiting factors. Assessment confidence for these SMUs varies and there is a high level of immediate threats that will affect viability in the future.
Endangered	Are not considered viable into the future and few, if any, populations will be able to persist without prompt pro-active management of threats and limiting factors. Assessment confidence for these SMUs varies and there is a high level of immediate threats that will affect viability in the future.

Chapter 4: Desired biological status

Desired status goals for population stratum are driven both by the ODFW mission "*to protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations*" and the Native Fish Conservation Policy goals (OAR 635-007-0503) to:

- prevent the serious depletion of native fish species by protecting natural ecological communities, conserving genetic resources, managing consumptive and non-consumptive fisheries, and using hatcheries responsibly so that naturally produced native fish are sustainable
- maintain and restore naturally produced native fish species, taking full advantage of the productive capacity of natural habitats to provide substantial ecological, economic, and cultural benefits to the citizens of Oregon
- foster and sustain opportunities for sport, commercial, and tribal harvest consistent with the conservation of naturally produced native fishes and responsible use of hatcheries.

For lampreys, these goals are interpreted as:

- for Pacific Lamprey, maintain the "prevalent" population stratum and improve the status from "common" to "prevalent" and from "absent"/"rare"/"limited" to "common" in all other strata, which should result in a "strong-guarded" SMU (Table 4.1)
- improve information on the other three lampreys so that their status can be assessed with greater certainty in the future (Table 4.2).

Challenges to realizing these goals include:

- potential worsening of existing limiting factors and threats (Chapter 5) at rates faster than management strategies can address these
- potential new limiting factors and threats that lampreys may experience in the future
- unknown efficacy of management strategies (Chapter 6) to addressing limiting factors and threats.

Table 4.1. Current status (Table 3.6) and minimum desired status for Pacific Lamprey, by population stratum and Species Management Unit.

Population strata	Current status	Desired status
Rogue/South Coast	Common	Prevalent
Coastal	Prevalent	Prevalent
Lower Columbia	Common	Prevalent
Willamette	Common	Prevalent
Mid Columbia	Limited	Common
Lower Snake	Rare	Common
Upper Snake	Absent	Common
Species Management Unit	**Sensitive**	**Strong-Guarded**

Table 4.2. Current status by population stratum (first seven rows) and desired status by Species Management Unit (SMU; last two rows) for Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey. The desired status for each population stratum is to be determined.

<table>
<tr><th>Population strata</th><th>Western River Lamprey</th><th>Western Brook Lamprey</th><th>Pacific Brook Lamprey</th></tr>
<tr><td>Rogue/South Coast</td><td></td><td rowspan="5">Undetermined</td><td rowspan="2"></td></tr>
<tr><td>Coastal</td><td rowspan="2">Undetermined</td></tr>
<tr><td>Lower Columbia</td><td rowspan="2">Undetermined</td></tr>
<tr><td>Willamette</td><td></td></tr>
<tr><td>Mid Columbia</td><td>Undetermined</td><td></td></tr>
<tr><td>Lower Snake</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>Upper Snake</td></tr>
<tr><td>SMU: Current status</td><td colspan="3">Sensitive</td></tr>
<tr><td>SMU: Desired status</td><td colspan="3">Strong-Guarded</td></tr>
</table>

Chapter 5: Key limiting factors and threats

The CPL defines limiting factors as the physical, biological or chemical conditions of the environment that constrain the abundance, productivity, diversity or distribution of a population or species. Table 5.1 shows a general characterization of limiting factors used in the CPL that fall within six management categories: 1) water quality, 2) water quantity, 3) access (passage), 4) physical habitat, 5) other species (i.e., predation, competition, disease, etc.), and 6) direct interactions with humans.

Note that limiting factors may affect lampreys in a complex manner. They do not always result in direct and immediate mortality. For example, a change in water temperature may cause an earlier or later seaward migration that puts anadromous lampreys in the ocean at the wrong time relative to food resources (Sharma et al. 2016; Clemens et al. 2019). Also, the cumulative effects of limiting factors on fishes can be greater than the sum of each limiting factor alone (Power 1997; Schreck 2002; Lange et al. 2018). Multiple limiting factors are often associated with common causes. For example, riparian condition may affect both physical habitat and water quality, and physical habitat may also affect water quality. Stream complexity affects hyporheic connections that influence stream temperature. Reduced water quantity is often associated with decreased water quality (i.e., increased temperature). Artificial obstructions can be linked to habitat simplifications and decreased water quality (Poff et al. 2007). Another example is the potential for expansion of non-native, predatory fishes into new areas that have modified, simplified habitats (Lawrence et al. 2012). Non-native fishes can negatively impact native fishes through predation, disease transmission, and habitat alteration (Sanderson et al. 2009).

Also note that Oregon has extensive regulatory protections in place for natural resources. State agencies and their general regulatory roles designed to benefit fish, wildlife, and their habitats are presented below, with notes on how these actions may benefit lampreys.

- ODFW regulates the take and release of fish and wildlife within Oregon, and implements the Oregon Endangered Species Act to recover and conserve imperiled fish and wildlife species. Regulation of the take and release of fish includes lampreys.
- The Department of State Lands (DSL) conserves and protects waterways in Oregon through regulation of fill and removal. DSL requires a "removal-fill permit" for activities that involve the removal or addition of material in wetlands and waterways, and coordinates with ODFW when issuing new permits. Regulation of fill and removal and consideration of lampreys in this process can result in avoidance or minimization of impacts to lamprey larvae that may be burrowed into waterway substrates.
- Local governments work with the Oregon Department of Land Conservation and Development to create and implement comprehensive land use plans that consider wetlands, riparian areas, and habitat, and guide residential and commercial development and other land use changes. ODFW's Conservation Strategy (ODFW 2016) is used to inform these plans. Most new development is directed into areas that are already developed. Development is strictly limited within Oregon's estuaries, including all major areas of seagrass and algae beds, intertidal flats, and tidal marshes, and other estuarine areas only allow low intensity development. Regulation of development on undeveloped lands can minimize impacts to all life stages of lampreys in fresh water.

- The Oregon Department of Environmental Quality (ODEQ) establishes and enforces state standards for air and water quality that give special consideration to species designated as endangered, threatened, or sensitive. High water quality is beneficial to lampreys.
- The Oregon Department of Forestry (ODF) implements the Oregon Forest Practices Act by regulating forest operations on all non-federal lands consistent with the sound management of soil, air, water, and fish and wildlife resources. Integrated forest management is conducted to maintain healthy, productive, and sustainable forest ecosystems and to achieve a concurrent balance among desirable wildlife and fish habitats, improved forest biological diversity, and revenue from timber harvest. Examples of some of the specific management actions by ODF include protection and enhancement of streams and management of sufficient stream buffer protections to meet water quality standards. Maintenance and enhancement of stream habitats, including water quality, can benefit all life stages of lampreys in fresh water.
- The Oregon Water Resources Department manages diversions and storage of surface and groundwater throughout Oregon, works with ODFW when issuing new water rights, and holds instream water rights (for ODFW) for the conservation, maintenance, and enhancement of aquatic and fish life, wildlife, and fish and wildlife habitat. Water is essential for lampreys to carry out their life cycles.
- The Oregon Department of Agriculture (ODA) regulates pesticides and establishes and enforces policies, guidelines, and requirements to prevent and control water pollution and soil erosion resulting from agricultural activities and on agricultural and rural lands. ODA administers the Agricultural Water Quality Management Program. Through this program, ODA works with Local Advisory Committees composed of ranchers, farmers, and stakeholders and Soil and Water Conservation Districts to develop plans for management of water quality and adopt regulations. High water quality is beneficial to all lamprey life stages.
- The Oregon Department of Geology and Mineral Industries regulates mining activities within Oregon and coordinates with ODFW when issuing new permits. The regulation of mining activities can minimize impacts of sedimentation and toxic pollutants into waterways where lampreys live, thus helping maintain high water quality that is beneficial to all lamprey life stages.
- The Oregon Department of Energy regulates energy facility siting within Oregon and coordinates with ODFW when issuing new permits. Coordination with facility siting can result in avoidance or minimization of impacts to lampreys and their habitats. Switches to alternative power sources can minimize global climate change.

In addition to a regulatory role, state agencies, landowners, organizations, and other government entities cooperate to improve fish habitat through non-regulatory programs and partnerships. Just a few examples are listed below.

- The Oregon Watershed Enhancement Board (OWEB) provides funds for restoration of watershed health. Healthy watersheds are necessary for lampreys to exist and thrive.
- OWEB and the Oregon Agricultural Heritage Commission also administer the Oregon Agricultural Heritage Program (OAHP). The OAHP offers voluntary incentives to ranchers and farmers to support maintenance or enhancement of both

agriculture and fish and wildlife on agriculture lands. Maintenance and enhancement of habitats adjacent to streams can benefit lampreys.

- The Tide Gate Partnership, which includes conservation and agriculture organizations, state, federal, and local agencies, counties, and landowners, was formed to provide a voluntary and collaborative plan with tide gate owners for the repair or replacement of tide gates. Improved functioning of tide gates or removal of tide gates may facilitate outmigration to the ocean by anadromous lamprey juveniles.
- ODA, ODEQ, ODF, the Oregon Health Authority, OWEB, and Oregon State University compose the Water Quality Pesticide Management Team, which oversees the Water Quality Pesticide Management Plan and Pesticide Stewardship Partnership (PSP) in Oregon. The PSP combines water quality sampling with local expertise to encourage voluntary changes in pesticides to improve water quality. High water quality is beneficial to all lamprey life stages.

State agencies continue to balance multiple, necessary societal uses for natural resources with fish and wildlife needs. The limiting factors identified in this chapter are for current conditions, which result from either current practices or legacy effects from past practices. Given the protective nature of Oregon's current natural resource regulations and the legacy component of current conditions, many limiting factors are expected to be addressed by restoration that builds upon existing state regulatory and non-regulatory efforts described above.

LIMITING FACTOR DETERMINATION

Limiting factors were determined by interviewing ODFW district staff (Clemens 2017), literature reviews, and professional judgment. This information was combined with distribution data for lampreys in Oregon (Figures 2.6 – 2.9; Table 2.3). Professional judgement was used to rank the limiting factors for each species by population stratum. Given this scale of assessment, specific restoration needs for any particular location within a population stratum will need to be determined during implementation.

Focus was placed on "key" limiting factors (ranked as primary or secondary limiting factors) and "unknown" factors that warrant more research. Rankings of limiting factors by ODFW for Pacific Lamprey (Table A8.1 in Appendix 8) were combined with those from the USFWS (USFWS 2018; Tables A4.2 and A4.3), resulting in the final rankings shown in Table 5.2. This was done by selecting the highest rank for a particular limiting factor and stratum between ODFW (Table A8.1) and the USFWS. Because lampreys overlap in their distributions (Chapter 2) and exhibit similar behaviors (albeit at different habitat scales), the limiting factors identified for Pacific Lamprey were used for Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey (Table 5.2). Adjustments were made for these latter three lampreys based on distribution and management practices.

Table 5.1. Limiting factors considered for lampreys. Note that limiting factors may occur at various spatial (e.g., freshwater, estuary, ocean) and temporal (larval, juvenile, adult) points within the lamprey life cycle.

Management Category	Limiting Factor	Description
Water Quality	Temperature	Altered physical, chemical, or biological water characteristics (e.g., temperature, dissolved oxygen, suspended sediment, pH, toxic pollutants in the water column and sediment, etc.) in freshwater, the estuary, and ocean
	Sedimentation	
	Toxic Pollutants	
	Other	
Water Quantity	Low	Reduced instream flows
	Altered Hydrology	Timing and magnitude of flows are shifted
Habitat Access	Inundation	Impaired access to spawning habitat, rearing habitat, or migration corridors (e.g., submerged due to impoundment, instream artificial obstructions, off-stream diversions)
	Upstream Passage	
	Downstream Passage	
Physical Habitat	Instream Structure	Altered structure and complexity of physical habitat within the bed and banks of the stream channel (e.g., large wood, boulders, beaver dams, and sinuosity affecting the composition of pools, riffles, and glides)
	Substrate	Altered sediment routing and composition of channel substrate, affecting availability of gravel for spawning and egg incubation; and silty sediment for burrowing (larval rearing)
	Peripheral Connection	Altered or inaccessible off-channel (peripheral) habitat such as estuaries, wetlands, side-channels, and floodplains
Other Species	Predation	Consumption, including injury, by another species affecting survival, fitness, or reproductive success in freshwater, estuaries, or the ocean
	Competition	Interaction with another species for a limited environmental resource (i.e., food, refuge, spawning gravel)
	Hybridization	Inter-breeding with other fishes resulting in reduced population fitness, reproductive success, or productivity
	Food Source	Availability of food, including prey, for nutrition and growth in freshwater and in the ocean
	Disease	Pathological condition resulting from infection
	Other	Other factors associated with a non-habitat biotic interaction that is not included on this list
Direct Interaction	Release	Unintended predatory, competitive, genetic, pathological, or other interaction(s) with fish, of the same or other species, that were released for management purposes (e.g., hatchery fish, translocations)
	Take [a]	Human removal, injury, or harassment of individuals (intentional or not) affecting survival, fitness, or reproductive success in freshwater, estuary, near-shore, or ocean locations, including influence on population demographics or diversity through selective pressure

[a] This description of "take" is for limiting factor consideration, and is not the same as the legal definition of "take" found in Oregon's statutes and administrative rules.

LIMITING FACTORS

Table 5.2. Primary limiting factors ("❶" in red cells), secondary limiting factors ("❷" in orange cells), and unknown limiting factors ("?" in tan-colored cells) for lampreys. Gray cells indicate the lack of primary, secondary, or unknown limiting factors. If specific species are indicated (PL = Pacific Lamprey; WRL = Western River Lamprey; WBL = Western Brook Lamprey; PBL = Pacific Brook Lamprey), the limiting factor only applies to that species of those present in the population stratum.

<table>
<tr><th>Management Category</th><th>Limiting Factor</th><th>Rogue/South Coast</th><th>Coastal</th><th>Lower Columbia</th><th>Willamette</th><th>Mid Columbia</th><th>Lower Snake</th><th>Upper Snake</th></tr>
<tr><th colspan="2">Species in Population Stratum:</th><td>PL, WBL</td><td>PL, WRL, WBL</td><td>PL, WRL, WBL, PBL</td><td>PL, WBL, PBL</td><td>PL, WRL, WBL</td><td>PL</td><td>PL</td></tr>
<tr><td rowspan="4">Water Quality</td><td>Temperature</td><td>❷</td><td rowspan="2">❷</td><td rowspan="2">❶</td><td rowspan="2">❶</td><td rowspan="2">❷</td><td rowspan="2">❷</td><td rowspan="3">?</td></tr>
<tr><td>Sedimentation</td><td></td></tr>
<tr><td>Toxic Pollutants</td><td>?</td><td>?</td><td>?</td><td>?</td><td>?</td><td>?</td></tr>
<tr><td>Other</td><td colspan="7"></td></tr>
<tr><td rowspan="2">Water Quantity</td><td>Low</td><td rowspan="2">❷</td><td rowspan="2">❷</td><td rowspan="2">❷</td><td rowspan="2">❶</td><td rowspan="2">❷</td><td rowspan="2">❷</td><td rowspan="2">❷</td></tr>
<tr><td>Altered Hydrology</td></tr>
<tr><td rowspan="3">Habitat Access</td><td>Inundation</td><td colspan="7"></td></tr>
<tr><td>Upstream Passage</td><td rowspan="2">❶</td><td rowspan="2">❶</td><td rowspan="2">?</td><td rowspan="2">❶</td><td rowspan="2">❶</td><td rowspan="2">❶</td><td rowspan="2">❶</td></tr>
<tr><td>Downstream Passage</td></tr>
<tr><td rowspan="3">Physical Habitat</td><td>Instream Structure</td><td rowspan="3"></td><td rowspan="3">❷</td><td rowspan="3">❷</td><td rowspan="3">❶</td><td rowspan="3">❷</td><td rowspan="3">❷</td><td rowspan="3"></td></tr>
<tr><td>Substrate</td></tr>
<tr><td>Peripheral Connection</td></tr>
<tr><td rowspan="8">Other Species</td><td>Predation: Pinnipeds</td><td>? PL</td><td>? PL, WRL</td><td>❶ PL, WRL</td><td>❶ PL</td><td></td><td></td><td></td></tr>
<tr><td>Predation: Birds</td><td rowspan="2"></td><td></td><td rowspan="2">❶</td><td>?</td><td>?</td><td></td><td></td></tr>
<tr><td>Predation: Non-native fishes</td><td>❶</td><td>❷</td><td>❷</td><td>?</td><td>?</td></tr>
<tr><td>Competition</td><td colspan="7"></td></tr>
<tr><td>Hybridization</td><td colspan="7"></td></tr>
<tr><td>Food Source</td><td colspan="7"></td></tr>
<tr><td>Disease</td><td>? PL</td><td>? PL</td><td>? PL</td><td>? PL</td><td>? PL</td><td></td><td></td></tr>
<tr><td>Other</td><td colspan="7"></td></tr>
<tr><td rowspan="2">Direct Interactions</td><td>Release</td><td colspan="7"></td></tr>
<tr><td>Take</td><td></td><td>? PL</td><td>? PL</td><td>? PL</td><td>? PL</td><td></td><td></td></tr>
</table>

Water Quality

Some aspects of water quality were identified as key limiting factors for all lampreys in six strata, and as an "unknown" in the Upper Snake stratum (Table 5.2). High water temperature is a current problem in many areas throughout Oregon. Sedimentation (including turbidity) and toxic pollutants from various land uses were noted less commonly (Clemens 2017; Table A8.2). Turbidity can be caused by erosion of stream banks, runoff from land, and dredging to deepen shipping channels (in areas like the mainstem Columbia River). Toxic pollutants from various sources include pesticides, herbicides, and industrial toxins. The Oregon Department of Environmental Quality (ODEQ) assessed 40.1% of Oregon streams and rivers for water quality.

Of these waters, 32.5% of the 46,036 stream and river miles assessed ranked as “good”, whereas 67.5% of the 46,036 stream and river miles ranked as “impaired” (ODEQ 2017).

Temperature

High water temperature is the most prevalent cause of water quality impairment (Table A8.2), and it was identified as a key limiting factor in six strata (Table 5.2). High water temperatures will expand in geographic area in the future (Appendix 5). During summer months, portions of many rivers in Oregon reach and exceed 70 – 80°F, which can be harmful to lampreys (Appendix 3). This observation has been recorded for several rivers throughout Oregon, which have long, uninterrupted stretches of high temperatures (> 68°F) during the summer (Fullerton et al. 2018)[6]. In some cases, water temperatures ≥ 68°F have been associated with biological problems in lampreys, up to and including death. However, lampreys may exhibit different temperature adaptations and thresholds across their distribution (Appendix 3).

Sedimentation

Turbidity is a process in which matter (fine matter of animal or plant origin and small rocks, silt, clay or sand) becomes suspended in the water column. Sedimentation is a subsequent process in which this matter is deposited onto the streambed in a downstream area. Matter can originate outside of stream channels or from bank erosion and hydrologic action on the streambed within stream channels.

Sedimentation is the second most prevalent cause of water quality impairment (Table A8.2). Although sedimentation provides deposits of sandy substrates that larvae use for rearing habitat (Chapter 2), too much sedimentation was identified as a key limiting factor in five strata (Table 5.2). Sedimentation has been identified as a symptom of poor habitat and can cover spawning gravel, developing embryos, and larval burrows (CRITFC 2011; Luzier et al. 2011). The assessment of sedimentation as a limiting factor for lampreys is influenced by knowledge of sedimentation effects on salmon, including covering developing embryos in redds and other sub-lethal impacts to juveniles (Redding et al. 1987). Sedimentation can also have indirect effects on aquatic organisms through impacts to aquatic food webs (Henley et al. 2000; Kemp et al. 2011).

Toxic pollutants

Lampreys may be harmed by various toxic pollutants (Table A8.3; Clemens et al. 2017a). However, two major unknowns remain about the effects of most toxic pollutants on lampreys: 1) the extent to which lampreys experience toxic pollutants throughout the landscape and across life stages, and 2) the ultimate effects of these pollutants on lamprey populations. For these two reasons, the effects of toxic pollutants on lampreys are identified as an unknown limiting factor across all population strata (Table 5.2). Pollutants (Table A8.3) can enter freshwater in many ways and we present these in three categories: 1) accidental spills, 2) past intentional use to eradicate some fishes in Oregon, and 3) legacy and on-going chemical discharge or applications in the environment.

[6] *The mainstem Rogue River is naturally warmer than other coastal rivers in Oregon during the summer.*

Accidental spills — An example of an accidental chemical spill occurred in 1999 in Fifteenmile Creek and was documented to have killed thousands of lampreys (Kostow 2002).

Past eradication — Non-game fishes including lampreys were historically considered to be undesirable "rough fish", and the OFWC and ODFW used a pesticide (rotenone) to kill them (Close et al. 1995, 2004; Downey et al. 1996; Kostow 2002; Sheoships 2014). These actions are counter to ODFW's current practices to conserve these native species. ODFW no longer uses rotenone to remove lampreys, and its use is restricted. State records on the historical use of rotenone are incomplete and unspecific (Kostow 2002). Interviews with tribal elders from various tribes in Oregon consistently indicate that rotenoning of lamprey occurred throughout Oregon, particularly the Umatilla, John Day, and potentially the coast as early as the 1940s and as late as the 1980s. The interviewed elders have associated these rotenone treatments with the decline of Pacific Lamprey (Close et al. 1995, 2004; Downey et al. 1996; Sheoships 2014).

Legacy or on-going chemical discharge or application — Controls and practices to limit the adverse use, effects, and entry into natural systems of toxic chemicals are always improving, but direct discharge (e.g., wastewater treatment overflow) and runoff (e.g., after pesticide and herbicide applications; from roads or urban areas) still occur into rivers and streams (Table A8.3). Larval lamprey bioaccumulate mercury, flame retardants, and pesticides in all areas within the Columbia River Basin (including the Lower Columbia, Willamette, and Mid Columbia strata) at levels that may be harmful to individuals and populations (Nilsen et al. 2015; Linley et al. 2016). Larval Pacific Lamprey in laboratory trials required significantly longer time to burrow into contaminated substrates from the Portland Harbor Super Fund site versus uncontaminated substrates, which could have implications for predator avoidance (Unrein et al. 2016). Adult Pacific Lamprey and Western River Lamprey parasitize various prey in the ocean (Table A3.5 in Appendix 3) and they may bioaccumulate toxins from them (Clemens et al. 2017a).

Other

This category includes any impairment in water quality beyond temperature, sedimentation, and toxic pollutants that could negatively impact lampreys. Examples include the absence of dissolved oxygen in the water, which is essential for lampreys to breathe; pH extremes; or excessive amounts of nutrients (eutrophication), and fecal bacteria that could negatively affect the health and survival of lampreys. Some examples of this category of water quality impairment are shown in Table A8.2. It is common knowledge among lamprey biologists that highly eutrophic waters often lack oxygen in the substrate and larval lampreys are not found in areas where this occurs. These other water quality impairments are not considered broadly limiting at this time.

Water Quantity

Low water availability is a current and key limiting factor for lampreys in all strata (Table 5.2). Winter flows are projected to decrease in the future (Figure A5.4). Drought, legal allocation of water for residential, municipal, agricultural, industrial, and commercial uses, and illegal diversions may yield little to no flow in parts of some river basins during summer and autumn. Regulated water from hydroelectric and flood control dams results in impounded river reaches, dampened peak river flows, and (in some cases) rapid dewatering and rewatering for operations (load following to make power) and maintenance. Seasonal changes in flow amplitude and timing may differ significantly from conditions to which lampreys have evolved.

Dewatering for in-water work and fish salvage can significantly, albeit temporarily, limit water quantity in particular river reaches. Dewatering can result in potential desiccation of redds, embryos, and larvae (Streif 2009; Liedtke et al. 2015; Maitland et al. 2015). Unnaturally rapid dewatering events near dams, water diversions, and instream projects "…can kill a large, but as yet unquantified, number of larval [lampreys] by stranding and subsequent desiccation or predation" (Clemens et al. 2017a), which can impact multiple year classes. Extrapolating the larval densities in Table A3.3, an estimated range of zero to millions of larvae may occur over a few acres of river bed. This suggests that dewatering of stream segments could have substantial consequences to larvae.

Habitat Access

Habitat access issues (e.g., upstream or downstream passage barriers, unscreened diversions, inundated areas) are the most significant limiting factor for lampreys in all strata (Table 5.2). Artificial obstructions are the most widely-recognized key factor limiting access for lampreys to habitats to complete their life cycles (Mesa and Copeland 2009; Moser and Mesa 2009; CRITFC 2011; Luzier et al. 2011; Clemens et al. 2017a). One example of the connection between artificial obstructions and lamprey includes tribal recollections of large runs of adult Pacific Lamprey in the Columbia River Basin prior to dam construction (Close et al. 2004). Impounded areas such as reservoirs behind dams (e.g., in the FCRPS) have eliminated habitat, reduced water velocities, increased downstream migration times (and increased predation rates; e.g., Poe et al. 1991; Zimmerman 1999). Another example occurs in the Deschutes River (Mid Columbia stratum), where Pacific Lamprey no longer occur above the Pelton-Round Butte dam complex and are therefore "presumed extirpated" (USFWS 2018)[7]. However, artificial obstructions for lampreys are not limited to hydropower dams on the mainstem Columbia River. Artificial obstructions for upstream-migrating adult lampreys and downstream-migrating larvae and juveniles occur in nearly all bodies of water where lamprey occur, used to occur or are likely to occur. Examples of artificial obstructions in Oregon include the 13 flood control dams in the upper Willamette River Basin operated by the U.S. Army Corps of Engineers (Sheer and Steel 2006), lowhead dams used for irrigation (e.g., in the Umatilla River; Close et al. 2009; Jackson and Moser 2012), a multitude of culverts throughout Oregon (e.g., Starcevich and Clements 2013; Chelgren and Dunham 2015), tidegates, and water diversions for irrigation and other uses (municipal and agricultural) that entrain or impinge larvae (Kostow 2002; Mesa and Copeland 2009; CRITFC 2011; Luzier et al. 2011; Clemens et al. 2017a). Characteristics of artificial obstructions for lampreys are presented in Appendix 8.

[7] *Pacific Lamprey has not been reintroduced above Round Butte dam because an assessment has deemed it highly unlikely that the surface collector in the forebay of that dam would successfully collect the progeny of translocated adults (Karchesky et al. 2013).*

Physical Habitat

Abundant, high-quality physical habitat is a fundamental aspect of thriving fish communities, including lampreys. Therefore, the prevalence of degraded physical habitats in streams, floodplains, and estuaries is a significant limiting factor for all lampreys in most strata (Table 5.2). Habitat degradation includes simplification of instream and floodplain habitats, which reduces habitat quantity and habitat quality. This can exacerbate water quality issues and can result in the inability of the stream to trap, retain, and accrue gravel for spawning or suspended sediment for rearing (as silt/sand pockets that can hold larval lampreys). Habitat simplification has occurred by diking/leveeing, armoring, and straightening channels, removal of riparian timber and instream large woody debris (Sedell and Froggatt 1984; Gregory et al. 2002; Clemens et al. 2017a), and other causes. Removal of riparian trees also removes shade and organic input into streams (Gregory et al. 1991), but this has been addressed by current riparian management practices. Riparian cover has been associated with the relative abundance of larval lamprey in the Pacific Northwest (Torgerson and Close 2004; Claire et al. 2007) and the eventual recruitment of these trees as large woody debris into streams, where they provide habitat (Sedell and Froggatt 1984; Gregory et al. 1991). Large woody debris traps and retains gravels and sediments that can be used for spawning and rearing, thereby providing habitats for all life stages (Streif 2009; Gonzalez et al. 2017). A lack of habitats for lampreys can be associated with vulnerability to predation. Stream simplification can disconnect stream-to-floodplain interactions, reducing nutrient input from land into streams and reducing in-stream habitat. Reduced stream sinuosity may decrease connections between the stream and groundwater that provide coolwater refuges and modulate stream temperatures.

Mining and splash damming left legacies of scoured substrates and potentially contaminated pilings in some basins (e.g., Umpqua Basin and John Day Basin, among others). Floodplain simplification has occurred in many basins as a result of dredging, timber harvest, fire, expanding road infrastructures, draining and filling of wetlands and backwater sloughs, and in some cases, river channelization through armoring and leveeing of banks. Some of these practices no longer occur and most are regulated, but legacy impacts remain and on-going practices can still impact aquatic habitats in which lampreys reside. Some specific examples of physical habitat problems in Oregon are described in Appendix 8.

Other Species

Predation

Predators of lampreys are listed in Table A3.4. Predation occurs on all life stages of all lampreys to various extents in all strata. Professional judgement indicates that predation by pinnipeds (seals and sea lions), birds, and non-native fishes are unknown or key limiting factors for lampreys (Table 5.2). In some streams of coastal Oregon, land mammals such as American Mink, River Otter and various bird species have been documented to depredate significant proportions of tagged adult Pacific Lamprey (Richard Litts, Tenmile Lakes Basin Partnership, pers. comm.; Starcevich et al. 2014; Table A3.4). With a few exceptions, the extent and magnitude of predation relative to the abundance of lampreys is unknown. Without bony skeletons, the keratinized teeth of lampreys (juveniles and adults) is often the only evidence observed in the guts of predators. Therefore the frequency of lampreys in the guts of predators is likely underestimated. The available information suggests the following trends in depredation of lampreys in Oregon:

- small artificial barriers can delay or block upstream and downstream migration of lamprey (Clemens et al. 2017a), thereby potentially subjecting them to greater depredation by various species
- the mainstem Columbia River is a predatory gauntlet for lampreys of various life stages that may become aggregated at the base of dams where they can be consumed by pinnipeds (Madson et al. 2017), birds (Merrell 1955; Zorich et al. 2011), and fishes
- river impoundments have created significant habitat for fish predators (Ward et al. 1995; Poe et al. 1991; Zimmerman 1999)
- downstream passage by larval and juvenile lampreys may subject an unknown proportion of them to injuries and disorientation that can result in depredation on them (Moser et al. 2015a; Clemens et al. 2017a)
- Smallmouth Bass can be an important predator of lampreys (e.g., Schultz et al. 2017)
- through a combination of illegal introductions, simplification of river habitats, and warming trends in rivers, the distribution of Smallmouth Bass in Oregon is expanding (Carey et al. 2011; Lawrence et al. 2012; Appendix 8).

Pinnipeds are an unknown or a key limiting factor for Pacific Lamprey and Western River Lamprey along Coastal Oregon and below dams. Predatory birds are an unknown or key limiting factor for lampreys in the Columbia River Basin. Non-native predatory fishes (primarily Smallmouth Bass) are an unknown or key limiting factor to lampreys in several strata in Oregon (Table 5.2).

Pinnipeds

Pinniped numbers in Oregon have increased over time (Figure 5.1). Significant pinniped predation of lampreys occurs in the Rogue/South Coast and Coastal strata, and it can vary by location, year, and species. California Sea Lions, Steller Sea Lions, and Pacific Harbor Seals have been estimated to consume Pacific Lamprey more than any other fish species in the Rogue River (Roffe and Mate 1984). A different study that sampled among sites within the Rogue/South Coast and Coastal strata revealed different findings: Pacific Lamprey was the fourth most common prey for Steller Sea Lions (Riemer et al. 2011)[8]. Various pinnipeds consume Western River Lamprey (Table A3.4).

Below Willamette Falls (Willamette stratum), an average of 493 (361 – 624; 95% confidence interval), 758 (531 – 984), and 1,254 (696 – 1,813) adult Pacific Lamprey were consumed by California Sea Lions during 2014, 2015, and 2016, respectively (Wright et al. 2014, 2015, and 2016). These consumption rates comprise 0.1 – 1.1% of the average, annual estimated total abundance of Pacific Lamprey at Willamette Falls, based on abundance estimates (Baker 2014, 2015; Baker and McVay 2015, 2016, 2017). These predation estimates are considered "…*minimum estimates, due to spatial and temporal undercoverage of the target population*" (Wright et al. 2016). In the tailrace of Bonneville Dam (mainstem Columbia River), California Sea Lions and Steller Sea Lions commonly depredate adult Pacific Lamprey: during 2002 – 2016, 0.4 – 25.1% of the total observed fish consumed by these animals was adult Pacific

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[8] *Roffe and Mate (1984) only identified and enumerated prey parts like lamprey teeth, ear bones fishes, and a few other structures. Riemer et al. (2011) identified and enumerated all body parts of prey, resulting in the identification and enumeration of additional prey species consumed by pinnipeds. This decreased the relative frequency of lamprey in pinniped diets (Susan Riemer, ODFW, pers. comm.).*

Lamprey (Madson et al. 2017). These estimates suggest that the level of predation by pinnipeds on anadromous lampreys may be considerable — hence the classification of predation by pinnipeds in the Lower Columbia and Willamette strata as a primary limiting factor (Table 5.2).

Birds

Several bird species consume lampreys (Table A3.4). Gulls, terns, and potentially cormorants are the most significant predators on larval and juvenile lampreys in the fresh and estuarine waters of the mainstem Columbia River. Impoundments have slowed the Columbia River and bird predators congregate near dam tailraces (Merrell 1955; Zorich et al. 2011). Gulls consume large numbers of Pacific Lamprey, Western Brook Lamprey (Merrell 1955; Zorich et al. 2011), and probably Western River Lamprey (Table A3.4) in the mainstem Columbia River. Below McNary Dam on the Columbia River, California Gulls, Ringbill Gulls, and Western Gulls primarily consumed Pacific Lamprey and Western Brook Lamprey (Merrell 1955). Fifty-five years since Merrell's research (1955), similar bird predation results were found at the John Day and The Dalles dams (downstream of McNary Dam). In 2010, the highest peaks in counts of California Gulls correlated with peaks in juvenile Pacific Lamprey outmigration through John Day Dam (Zorich et al. 2011). In that same year at John Day Dam, juvenile Pacific Lamprey were the second most abundant prey of California Gulls (behind smolts), and at The Dalles Dam they were the most abundant prey of California Gulls (Zorich et al. 2011). In the Columbia River estuary, large colonies of gulls, terns, and cormorants reside on dredge spoils and consume outmigrating larval and juvenile lampreys. Lampreys comprised < 1.9% of the diet samples of Caspian Terns (e.g., Collis et al. 2002). Double-crested Cormorants also consume lampreys (Table A3.4). However, no lampreys were detected in 327 stomach samples from Double Crested Cormorants collected during 2012 – 2015 from Tillamook Bay and the Umpqua River estuary (Coastal stratum) and from Rogue River estuary (Rogue/South Coast stratum; ODFW unpublished data). Predation by birds on larval lamprey may be considerable, but the percentage of the overall population(s) of lamprey affected is unknown (Table 5.2).

Non-native fishes

A number of native and non-native fish predators consume lampreys (Table A3.4). Predation by native fishes is a natural occurrence of balanced ecosystems that can become unbalanced in perturbed ecosystems[9]. Within the mainstem Columbia River, during 2006 – 2016, 16.7% of the 8,433 native Northern Pikeminnow examined had consumed lamprey (Storch et al. 2013; Williams et al. 2018; M. Barr, Columbia River Predation Studies, ODFW, unpubl. data). The focus of the CPL is on non-native species. Non-native, warmwater fish predators include Smallmouth Bass, Largemouth Bass, Walleye, crappies, bullhead catfishes, etc.

Empirical evidence exists for bullhead catfishes and Walleye depredating lampreys (Table A3.4), and anecdotal evidence indicates that Walleye can consume larval lampreys in such quantity that they regurgitate them upon being caught by anglers. However, Smallmouth Bass are thought to be the most significant non-native fish predator of lampreys. Smallmouth Bass

[9] *Increased predation by native Northern Pikeminnow on salmon smolts occurs in impounded areas and in warmer climate regimes (Ward et al. 1995; Petersen and Kitchell 2001).*

have been intentionally (and in many places illegally) introduced throughout the Pacific Northwest, and exist throughout Oregon (Carey et al. 2011). Increasing evidence is being reported of their expanding distribution throughout Oregon (Appendix 8), and feeding habits on larval and juvenile lampreys drove the ranking as a key factor limiting particular strata (Table 5.2). The range of Smallmouth Bass may expand with "…*climate- or land-use-related stream warming*" (Lawrence et al. 2012). Professional opinion suggests that Smallmouth Bass may be consuming large numbers of lamprey in various parts of Oregon (Appendix 8), thus leading to the identification of non-native fish as a key limiting factor in some strata. In other strata, where less information is available and non-native fishes are present, predation by them is ranked as "unknown" (Table 5.2).

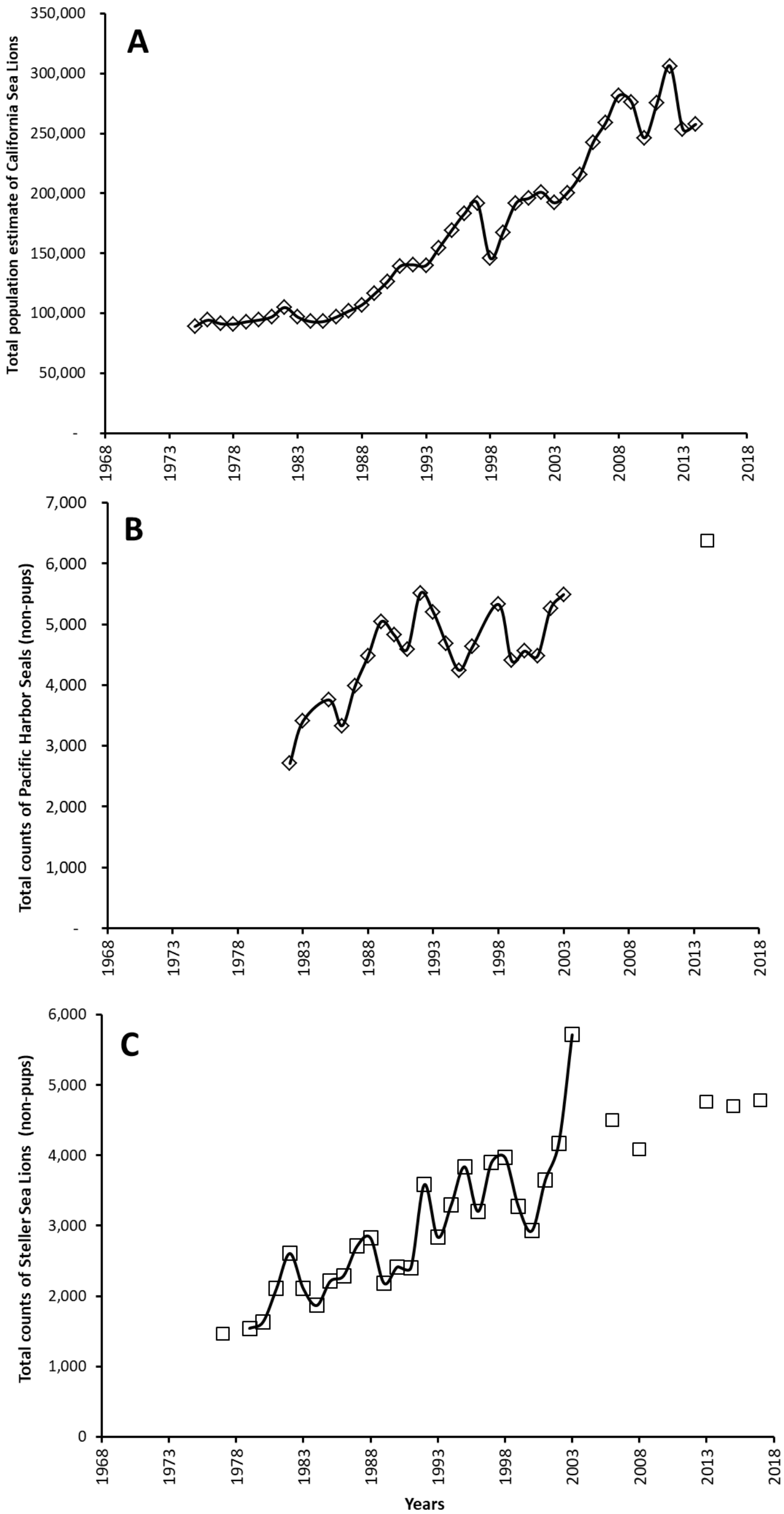

Figure 5.1. (**A**). Total population estimates of the U.S. stock of California Sea Lions (from Laake et al. 2018). (**B**). Total counts of Pacific Harbor Seals (non-pups) in Oregon (from Brown et al. 2005 and ODFW unpubl. data). Surveys were either not conducted or the data have not been finalized between the time series ending in 2003 and the data point (square) in 2014. (**C**). Total counts of Steller Sea Lions (non-pups) in the Oregon rookeries of the Eastern Distinct Population Segment (ODFW unpbul. data). The six data points (squares) indicate year estimates discontinuous from the 1979 – 2003 series.

Competition, Hybridization, Food source, Disease, and Other

Competition with other species and disease from them are not thought to be limiting factors for lampreys in Oregon. Similarly, hybridization, food source, and other biotic factors are not thought to be limiting factors for lampreys in Oregon.

Direct Interactions

Release

The release of lampreys is not currently a limiting factor in Oregon. Releases of hatchery Pacific Lamprey and the movement of Pacific Lamprey from one location for release in another (i.e., translocation) are purposeful and positive management methods that are used to achieve various objectives (e.g., CRITFC 2011; CRITFC et al. 2018). Translocation has been used as a "stopgap" measure until passage improves for lamprey to become self-sustaining (CRITFC 2011). However, releasing lamprey may unintentionally have negative effects on local, naturally-producing, native lampreys. For example, hatchery salmonids may impact wild fish through competition, disease transmission, and genetic effects that can reduce the overall reproductive success and productivity of naturally spawning populations (ORAFS 2017). Competition, disease, genetic effects of released hatchery lamprey and translocated lamprey are not limiting factors; nearly 20 years of translocation by tribes has yet to reveal any unintentional negative effects to lamprey (Aaron Jackson, CTUIR, pers. comm.). As this work proceeds, further investigation and caution is warranted.

Pacific Lamprey is the only lamprey species that have been artificially-propagated in significant numbers at hatcheries (Jolley et al. 2015; Barron et al. 2016; Lampman et al. 2016; CRITFC et al. 2018). Hatchery rearing of Pacific Lamprey is conducted to supplement dwindling population(s) in the mid and upper Columbia River basins and as a source of fish to be used for research — to replace take and use of wild Pacific Lamprey (CRITFC et al. 2018). In a sequential, phased approach, CRITFC and its member tribes plan to use the results from research on releases of hatchery lamprey (and translocated adults, addressed below) "…*to inform development of restoration actions*" (CRITFC et al. 2018). The Yakama Nation has proposed to produce and release hatchery larval Pacific Lamprey into the Yakima subbasin (Washington), and the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) have proposed to produce and release them into the Tucannon River (Washington) and into the mid- to lower portions of the Walla Walla River, including in Oregon (CRITFC et al. 2018). Hatchery larval Pacific Lamprey to be released into the Walla Walla River may originate from facilities in Washington or from a repurposed South Fork Walla Walla facility near Milton-Freewater in Oregon (CRITFC et al. 2018). To date, hatchery-rearing of Pacific Lamprey has not resulted in releases into the wild (Aaron Jackson, CTUIR, pers. comm., July 2019). No known releases of hatchery Pacific Lamprey have occurred into Oregon waters. ODFW therefore concludes that hatchery Pacific Lamprey are not negatively affecting naturally-produced fish at this time. This warrants further consideration if hatchery lamprey become present in Oregon[10].

[10] *Hatchery lamprey are only considered a limiting factor if they negatively impact naturally-producing lamprey. Careful, strategic use of hatchery lamprey can certainly provide management benefits. Although the CPL does not recommend conservation hatcheries for any lamprey species at this time, this should not preclude potential ODFW involvement in these in the future.*

Translocation is a restoration strategy employed by various tribes to reintroduce adult Pacific Lamprey back into formerly occupied basins or to supplement limited numbers of existing lamprey (CRITFC 2011; CRITFC et al. 2018; Ward et al. 2012; K. Dirksen and T. Wakeland, CTGR, pers. comm.). Portland General Electric has also conducted translocation within the Clackamas River (Ackerman and David 2018). Translocation occurs by collecting adult Pacific Lamprey from locations low in the Columbia River Basin and transporting them past artificial obstructions for releases in parts of the upper subbasins. Translocation by tribes of adult Pacific Lamprey (including donor and receiving locations) occurs in the Lower Columbia, Willamette, Mid Columbia, and Lower Snake strata. Translocation is: "…*intended to be a stop-gap measure to maintain lamprey presence while known limiting factors and critical uncertainties are addressed*" (CRITFC et al. 2018). Translocation has been associated with increased numbers of larval and juvenile lamprey and immigrant adults in Oregon (in the Umatilla River) and Washington (in the Yakima River), and in larval and juvenile lamprey in basins receiving adults in Idaho (Ralph Lampman, Yakama Nation, pers. comm.; Ward et al. 2012; CRITFC et al. 2018). Translocation is typically used for reintroduction purposes, so most of these concerns for the "receiving" population (competition, disruption of genetic stock structure) do not apply because there is no functional receiving population. In addition, concerns of transmission of disease to other lampreys is not a concern because of the ongoing pathogen screening and inoculation with antibiotics (oxytetracycline) to prevent diseases that occurs (CRITFC et al. 2018; Jackson et al. 2019).

Take

Take of lampreys is not currently believed to be a primary or secondary limiting factor for lampreys, but actual impacts for all forms of take need further assessment. Take can occur for many purposes, including fisheries for personal use (adult Pacific Lamprey), harvest for cultural use by tribes (adult Pacific Lamprey), illegal take for use as bait for other fishes (see Table A10.1), translocations from one location to benefit a receiving location (adult Pacific Lamprey), broodstock collection for hatchery programs (i.e., take of adult Pacific Lamprey to use their eggs and milt for subsequent artificial fertilization and propagation)[11], scientific collection (all lamprey species), and other uses (all lamprey species). The potential negative effects of take include a reduction in abundance for populations and potential shifts in distribution and diversity.

Fisheries (harvest) occur for adult Pacific Lamprey in four strata (Table A8.4). This harvest is primarily by tribal fishers, with some non-tribal harvest occurring at Willamette Falls (Figure A8.1). Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey are not currently known to be harvested for tribal or personal use. The proportion of the Pacific Lamprey population(s) harvested in the Coastal stratum is unknown (Table A8.4). Most of the harvest of Pacific Lamprey in Oregon occurs at Willamette Falls (Willamette stratum; Table A8.4), where take is closely managed and current harvest numbers are a fraction of historical harvest numbers (Figure A8.1). Relatively fewer lamprey have been harvested from the Mid Columbia and Coastal strata (Table A8.4). However, when harvest is compared as a percentage of the total abundance of lamprey at each harvest site, the harvest rate of adult Pacific Lamprey from the two locations in the Mid Columbia (Cushing Falls and Sherars Falls, with average annual harvest rates of 7.5% and 19.1%, respectively) outpaces that of Willamette Falls (average annual harvest rate = 2.7%; Table A8.4).

[11] *Tribal take in the Columbia River Basin follows specific guidelines (summarized in Appendix 8).*

As previously described for the release of fish as a potential limiting factor, broodstock collection for hatchery programs and translocations occur within the geographic area of this plan. These actions result in the removal of Pacific Lamprey from natural production in the location from which they are removed. Further details on translocation are presented in Appendix 8.

Scientific take occurs for all life stages of Pacific Lamprey, Western River Lamprey, and Western Brook Lamprey in six strata (Table A8.5). Although no option previously existed in the permitting system to select for Pacific Brook Lamprey[12], this species was likely lumped with Western Brook Lamprey. A total of 743 projects during 2002 – 2017 obtained scientific take permits from ODFW that included lampreys (database records began in 2002). Some projects targeted lampreys, but most lamprey take was incidental to projects targeting other fishes. In these projects 199,304 lampreys were collected for research, monitoring, education, and rescue/salvage activities. Of these, 8,621 were lethally sampled, and an additional 14,642 were indirect mortalities (total mortalities = 23,263 lampreys). This computes to a 10.9% mortality rate for all lampreys taken for scientific purposes (Table A8.5). Relative mortality was highest for Western Brook Lamprey (13.4%), followed by Pacific Lamprey (11.9%; Table A8.5). The composition of the total mortalities (23,263 lampreys) across 16 yrs (2002 – 2017) of scientific take, by species and population stratum, is presented in Table A8.6. The vast majority of these mortalities were Pacific Lamprey. Most of the Pacific Lamprey mortalities occurred in the Coastal stratum (54.9% of the 23,263 mortalities = 12,762 Pacific Lamprey; Table A8.6). The impact of this aggregated scientific take on lamprey populations across years is difficult to assess because the relative proportion of these populations being impacted is unknown.

Although lamprey take numbers for multiple purposes are known in most cases, they are not associated with strata- or population-specific impacts because overall abundances are not known. Also, no information exists to suggest the maximum level of take that Pacific Lamprey can sustain before it becomes a key limiting factor for them. This leads to the conclusion that the effect of take on Pacific Lamprey within four strata, including the Coastal, Lower Columbia, Willamette (Willamette Falls), and Mid Columbia is “unknown” (Table 5.2) and warrants more investigation.

Summary

Based on the severity of limiting factors, the number of strata impacted (Table 5.2), and best professional judgment, ODFW identified the five most important limiting factors for lampreys in Oregon. These are based on the best current available information and presented here in the order of relative impact:

1. access (passage and screening at artificial obstructions),
2. water quantity (reduced flows, flow management),
3. water quality (high water temperature, sedimentation),
4. physical habitat (stream and floodplain degradation), and
5. predation by other species (particularly non-native fishes).

[12] *This situation has since been remedied: an option now exists for selecting Pacific Brook Lamprey in the permitting application and reporting system.*

The impact of some limiting factors including take, predation by other species, disease, and water quality (e.g., toxic pollutants) is unknown in some strata for lampreys (Table 5.2) and warrants further investigation.

COMPLEX, LARGE-SCALE THREATS

The CPL defines threats as processes or actions (human-induced or natural) that have the potential to act on or create limiting factors that constrain the abundance, productivity, diversity or distribution of populations or species. Three complex, large-scale threats can negatively impact the status of population strata through exacerbation of limiting factors. These threats include climate change, estuarine and ocean conditions, and development relative to human population growth (Maas-Hebner et al. 2016). Two of these, climate change and estuarine and ocean conditions, are identified by the USFWS as threats to Pacific Lamprey throughout their range (Table A4.3). The USFWS ranked climate change as a “moderate” threat in portions of the Coastal and Rogue/South Coast stratum, a “high” threat in the Mid Columbia stratum, and an unranked, albeit major threat in the North Pacific Ocean, which ostensibly includes Pacific Lamprey from all strata in Oregon. In addition, ocean conditions was an unranked, albeit major, threat in the North Pacific Ocean (USFWS 2018).

Because of the national and global scales at which complex, large-scale threats operate and the uncertainty in how these threats will be realized by habitats, other species, and lampreys, specific impacts are challenging to predict. The following presents a high-level, qualitative overview of how these threats may influence key limiting factors of lampreys in Oregon.

Climate change

The effects of climate change are likely to increase the cumulative impacts of a variety of stressors on stream systems (Williams et al. 2015a).

Climate change is a key threat to cold-water fishes (Trout Unlimited 2015; Williams et al. 2015a), including lampreys (Moyle et al. 2013). Abundant evidence suggests that many environmental and ecological changes will occur in Oregon by the mid and late 21st century. Climate change will exacerbate existing limiting factors to lampreys in Oregon in many indirect and direct ways (Table A9.1). The effects of climate change can have complex, cumulative, and potentially synergistic effects that are difficult to predict (Table A9.2). What follows are the Methods, Results and Discussion for projections of future distribution for Pacific Lamprey from SDMs that incorporate climate change (details are presented in Appendix 5).

Methods

Species Distribution Models were used to predict the probability of occurrence of Pacific Lamprey in Western Oregon in 2040 and 2080 (Appendix 5). A lack of distribution data prevented modeling distribution of Pacific Lamprey in Eastern Oregon.

Results and Discussion

The following trends are evidential in the SDM for Pacific Lamprey:

- projected future probabilities of occurrence (distribution) of Pacific Lamprey generally decrease from present (Table 5.3; Figure A5.9A) to 2040 (Table 5.3; Figure A5.9B) and 2080 (Table 5.3; Figure A5.9C) in all four strata (Rogue/South Coast, Coastal, Lower Columbia, and Willamette) [13]
- projected decreases in future probabilities of occurrence for Pacific Lamprey are most obvious in the mainstem Willamette River (Table 5.3; Figure A5.9), where stream temperatures are projected to increase significantly (Figure A5.2)
- decreases in projected future distributions of Pacific Lamprey are accentuated in the eastern portion of the four strata, in proximity to the Cascade Mountain Range and major artificial obstructions (Table 5.3; Figure A5.9).

Table 5.3. Distance of suitable habitat (miles) and the proportional change in this suitable habitat when the probability of occurrence is either ≥ 50% or ≥ 80%. Distance was calculated for baseline and across 2040 and 2080 climate projections. Population stratum abbreviations: RSC = South Coast; CST = Coastal; LC = Lower Columbia; WI = Willamette.

Population stratum	Probability ≥ 50%				Probability ≥80%			
	Baseline	**2040**	**2080**	***% Change* to 2080**	**Baseline**	**2040**	**2080**	***% Change* to 2080**
CST	10,578.75	10,265.89	10,273.44	*2.88*	3,827.29	3,508.90	3,404.62	*11.04*
LC	1,304.57	1,087.24	978.51	*24.99*	219.47	163.70	93.62	*57.34*
RSC	1,887.05	1,828.25	1,822.44	*3.42*	571.61	551.89	57.61	*5.45*
WI	2,834.04	2,183.03	1,872.21	*33.93*	95.97	86.10	81.98	*14.58*

Estuarine and ocean conditions

"*…the adult phase of the Pacific Lamprey in the marine environment is the principal factor in predicting returns to the Columbia River*" (Murauskas et al. 2013).

Estuarine and ocean conditions may influence the abundance of anadromous Pacific Lamprey and Western River Lamprey in many indirect and direct ways that can be categorized in two ways: interactions of climate change with estuarine and ocean conditions (Table A9.1), and oceanographic regime changes. Estuarine and ocean conditions may have little to no impact on resident Western Brook Lamprey and Pacific Brook Lamprey, with the exception of how these threats impact the anadromous Western River Lamprey with which they may interbreed (Appendix 3). Interactions of climate change with ocean conditions occurs through increases in sea surface temperatures, temperature stratification and deoxygenation by depth, increased acidification of seawater, decreased and delayed upwelling, and decreased prey availability. These effects of climate change may impact anadromous lampreys in ways that are not understood. The warming of ocean waters by climate change has been associated with the movement of a number of marine fish and invertebrate species into deeper depths and towards the north and south poles (Pinsky et al. 2013; Cheung et al. 2015). Some of these species have been documented prey of lampreys (Table A3.5). This suggests that as the prey of Pacific

[13] *Future projections of distribution appear bleak in some areas of Oregon, although the survey effort in some strata has been fairly low (see "Survey effort" column in Table 3.2).*

Lamprey and Western River Lamprey change distributions in the ocean, these lampreys may also change their distributions to follow them or they may adapt to prey on different species, including those not historically encountered with any frequency. Oceanographic regime change towards a cool phase in the ocean off the Pacific Northwest is associated with increased upwelling, increased abundance of prey (more zooplankton with high-fat content, and more small fish), increased survival of juvenile salmonids, and reductions in their predators — leading to relatively high growth and survival of young salmon and steelhead, and ultimately more of them[14]. Conversely, warm regimes in the Pacific Northwest are related to decreased salmon production (Mantua et al. 1997; Peterson and Schwing 2003).

If regime changes influence the abundance of prey that anadromous lampreys feed on, these regimes may influence the relative abundance of anadromous lampreys. However a few key differences between salmonids and lampreys make predictions of lamprey abundance in relation to regime phase challenging. For instance, it is not known whether initial entry of juvenile Pacific Lamprey into the ocean from Oregon (which may be experiencing one regime) is more important than some time after they have migrated to the Bering Sea (which may be their primary feeding grounds [Appendix 3]) — and which would be experiencing a different oceanographic regime. Also, Pacific Lamprey do not home to their natal streams (Appendix 3), which makes it challenging to attempt to link oceanographic regimes with growth and survival of young Pacific Lamprey. By contrast, Western River Lamprey occur in estuaries and the nearshore ocean (Appendix 3). This leads to the hypothesis that, similar to salmon, the abundance of adult Western River Lamprey returning to Oregon may be highest during cool oceanographic regimes.

Development relative to human population growth

"*Land-use and land-cover changes affect local, regional, and global climate change processes*" (Brown et al. 2014).

"*Anthropogenic land use will likely present a greater challenge to biodiversity than climate change this century in the Pacific Northwest*" (Wilson et al. 2014).

These quotes identify challenges to understanding and managing complex interactions between development and climate change and opportunities for managing lamprey habitats. The human population in Oregon has been increasing (Figure 5.3). With increases in population come increases in water use and changes in land use, which have the potential to subsume or fragment lamprey habitats (including water quantity and quality). The extent of development, as measured by the percentage of impervious surfaces (asphalt and concrete paved surfaces) and the number of road-stream crossings, is already substantial (Figure A5.7). Most of the human population in Oregon lives west of the Cascade Mountain range, and along the I-5 transportation corridor (ISAB 2007). In particular, the Portland, Salem, metropolitan areas to the west of the Cascades, and the Bend metropolitan area to the east have the greatest population densities in Oregon (ISAB 2007). In the future water use is expected to increase for

[14] *By contrast, in the Gulf of Alaska, cool regimes yield decreased salmon production whereas* warm *regimes yield increased salmon production. Hence an asynchrony in phasing of salmon productivity occurs between Alaska and the Pacific Northwest during a regime change (Mantua et al. 1997; Peterson and Schwing 2003).*

hydropower, residential, municipal, industrial, commercial, recreational, and agricultural needs (ISAB 2007). The magnitude of water withdrawals in Oregon is higher in the arid areas of Eastern Oregon (Franczyk and Chang 2009). Water quality is vulnerable in the proximity of the mainstem Columbia River where population and agricultural densities are high (Chang et al. 2013). In an assessment of water supply, demand, and quality, water supply was found to be more important than water quality in the Upper Snake River Basin, whereas water quality was more important than water supply in the Willamette Basin (Chang et al. 2013). Water quantity will be a primary concern in the Mid Columbia, Lower Snake and Upper Snake strata, whereas water quality will be a primary concern in the Willamette and Rogue/South Coast strata (Chang et al. 2013; Appendix 5). Land development is also expected to increase with the human population in the future. Deforestation, soil erosion and sedimentation into streams, removal of trees that shade streams (keeping them cool), and simplification of habitat through a lack of recruitment of trees to the streams (Figure A5.6) and channelization are likely with increased development (Brown et al. 2014). Increased land development can translate into increased road density and stream crossings (often resulting in fish passage challenges), and an increase in impervious surfaces (Figure A5.7) which can increase pollutant runoff into streams from vehicles and industrial manufacturing (Brown et al. 2014). Development can exacerbate limitations of physical habitat, water quality, and habitat access in all strata, particularly in the densely-populated and growing metropolitan areas within the Lower Columbia, Willamette, and Mid Columbia strata. Absorption of solar energy by impervious surfaces in urban areas leads to localized “heat islands” that can affect local climate (Brown et al. 2014). Development has complex, cumulative, and synergistic associations with climate change, drought, and water use. Urban land can affect local climate and land development can affect local temperatures and the amount of water retention and use, and alter carbon retention and release, thus affecting local amounts of greenhouse gases that contribute to climate change (Brown et al. 2014).

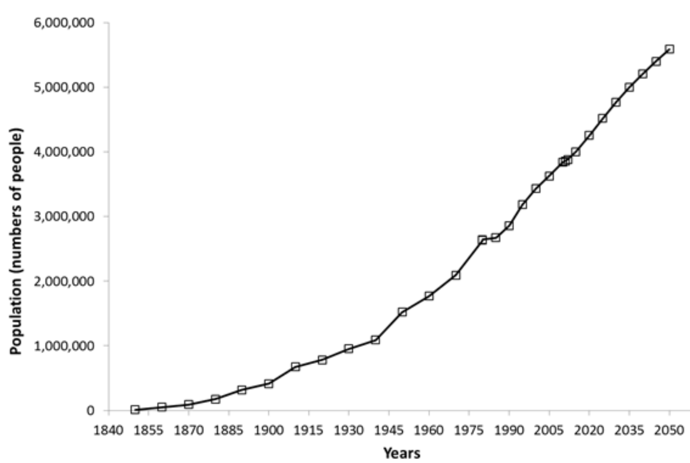

Figure 5.3. Human population estimates for Oregon, 1840 – 2050. Data from World Population Review (2018) and DAS (2018).

CONCLUSIONS

This chapter has identified key limiting factors, unknowns, and complex, large-scale threats to lampreys. Lampreys may experience worsening of limiting factors and new limiting factors in the future. Analyses of complex, large-scale threats indicates pervasive and interactive impacts to ecosystems that will exacerbate factors limiting lampreys, such as water quantity, water quality, and other environmental factors (Appendix 5). This suggests the need to monitor climate change impacts to lampreys (e.g., via SDMs; Appendix 5); improve understanding of how estuarine and ocean conditions will affect recruitment of anadromous lampreys; improve predictions of how land development relative to human population growth will affect freshwater habitats of lampreys; and improve our understanding of the interactive effects of these threats on factors limiting lampreys. Deliberate and consistent efforts, funding, and coordination among entities will be necessary to carry out management strategies and to offset additional impacts of these threats. Monitoring and adaptively managing threats and limiting factors in meaningful and feasible ways will be challenging. Management strategies to address limiting factors and threats are discussed in Chapter 6 and RME to address unknowns is discussed in Chapter 7.

Chapter 6: Management strategies

To achieve desired statuses for lampreys, key limiting factors will need to be addressed for each population stratum (Table 5.2). Management strategies were identified to address key limiting factors and compensate for the impacts of complex, large-scale threats that will exacerbate these factors[15]. Management strategies were prioritized by considerations of the estimated impact each would have on addressing limiting factors (Table 6.1). Each consideration was ranked "Low" (score = 1), "Varies" (1), "Moderate" (3) or "High" (4) for each management strategy. All were weighted equally and summed to determine priority (Table 6.1). Tied scores were ordered by professional judgment. Implementation will require continuation of existing strategies and beginning new ones (Table 6.2). Existing strategies include managing take, providing access to habitat (i.e., passage), and managing for wild lamprey production in certain areas of the Coastal strata (Table A10.1). ODFW will identify, acknowledge, and support management strategies beneficial to lampreys.

Table 6.1. Prioritization of management strategies (left column; high priority at top, low priority at bottom) and the estimated impact to address limiting factors for lampreys.

	Feasibility	Benefits to lampreys	Benefits to other strategies	Addresses key limiting factors	Work already being done by ODFW for other purposes?
Education & outreach	High	High	High	High	No
Passage & screening	Varies	High	High	High	Yes
Protect & restore habitat	Varies	High	High	High	Yes
Water conservation	Low	High	High	High	Yes
Translocation	Varies	High	High	Moderate	No
Establish in-water work BMPs	High	Varies	Moderate	Moderate	No
Modify non-native angling regulations	Moderate	Low	Low	High	Yes
Pinniped management	Varies	Varies	Low	High	Yes

[15] *Primarily climate change and human development impacts to freshwater habitats. Note that threats from ocean conditions may have large impacts on anadromous lampreys; however, there is no ability to mitigate impacts through local management actions and coordination with other entities will be needed to develop policies at larger scales to address this threat.*

Table 6.2. Eight management strategies (top row, arranged from left per Table 6.1) to address limiting factors and complex, large-scale threats (climate change and development by humans) to lampreys (left column). Management strategies are for all lampreys unless indicated otherwise. In the top row, "new" = novel strategy for ODFW; "existing" = strategy already being employed by ODFW. The population strata (PS) include: LC = Lower Columbia, WI = Willamette, MC = Mid Columbia, LS = Lower Snake, and US = Upper Snake.

<table>
<tr><th></th><th>Education & outreach (New)</th><th>Passage & screening (New & Existing)</th><th>Protect & restore habitat (Existing)</th><th>Water conservation (Existing)</th><th>Translocation (New)</th><th>Establish in-water work BMPs (New)</th><th>Modify non-native angling regulations (New & Existing)</th><th>Pinniped management (Existing)</th></tr>
<tr><td>Take</td><td rowspan="7">Addresses all limiting factors (all PS)</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td></td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td>Other Species</td><td rowspan="4">Addresses limiting factors pertaining to predators of, and habitat for, Pacific Lamprey (LC, WI, MC, LS, US)</td><td>Addresses predation (all PS)</td><td>Addresses predation on Pacific Lamprey & Western River Lamprey (LC)</td></tr>
<tr><td>Water Quality</td><td rowspan="3">Addresses limiting factors pertaining to habitat (all PS)</td><td rowspan="5">Addresses limiting factors pertaining to habitat (all PS)</td><td rowspan="3">Addresses limiting factors pertaining to habitat (all PS)</td><td rowspan="5">Addresses limiting factors pertaining to habitat (all PS)</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td>Water Quantity</td></tr>
<tr><td>Habitat Access</td></tr>
<tr><td>Physical Habitat</td><td></td><td></td><td></td></tr>
<tr><td>Climate Change; Development</td><td>Addresses habitat</td><td>Addresses habitat</td><td>Addresses predators of, and habitat for, Pacific Lamprey</td></tr>
</table>

The following describes each of the eight strategies identified above.

1. Education and outreach

This strategy covers all lamprey species across all strata (Table 6.2). Education and outreach covers all facets of the biology of lampreys, cultural importance (Pacific Lamprey), and ecological importance (all lampreys). In addition, this action can provide information on the status, limiting factors, threats, management strategies, Best Management Practices (BMPs), and RME for lampreys. Education and outreach is needed for both the general public and ODFW biologists. Many people are unaware that lampreys exist. Of those who know of lampreys in Oregon, many associate them with the invasive and nuisance Sea Lamprey of the Great Lakes (Clemens et al. 2010; Maitland et al. 2015; Clemens et al. 2017a). The following quote captures this lack of awareness: "*Because of this lack of awareness, implementation of best management practices for lamprey in monitoring, habitat restoration, and fish passage and diversion structures is underappreciated and lags behind that of other fishes. Awareness of Pacific Lamprey* [and other Oregon lampreys] *will be necessary to advance conservation and restoration efforts for* [these] *species*" (Clemens et al. 2017a). Interviews with ODFW district staff suggested that education and outreach is needed throughout Oregon (Clemens 2017). The following approach and tactics have been identified to fill this void in the awareness of citizens and biologists of all aspects of lamprey biology, limiting factors, status, management strategies, and RME needs.

Approach with general public:

This ***recommended***, new strategy for ODFW aims to educate and raise awareness about lampreys to as many Oregonians as possible, such that diverse ethnicities, genders, ages, and communities are reached. The following tactics are examples of what can be implemented:

Develop high-quality, information handouts and brochures for dissemination at ODFW headquarters, district field offices and hatcheries, museums, aquaria, and hydropower visitor centers (e.g., the Visitor Center at Bonneville Dam), and other, similar areas.

- develop high-quality information displays at select ODFW field offices and hatcheries, museums, aquaria, and hydropower visitor centers (e.g., the Visitor Center at Bonneville Dam), and other, similar areas
- develop information displays and/or signage to accompany locations where Lamprey Passage Structures (LPS) or other modifications beneficial for lamprey are in place
- update and further develop ODFW websites that house information on Oregon lampreys, and build web links to other key information websites (e.g., the PLCI)
- incorporate education and outreach material into social media platforms
- partner with tribes, the USFWS, academic extension services, watershed councils, the Oregon Zoo, and other entities as appropriate to develop new and/or adapt existing curricula and materials for in-person education and outreach about lampreys to Oregonians, and to collect and display lamprey specimens in a humane manner for hands-on experiential learning at various venues.

Approach with tribes, watershed councils, agencies, and other partners:

Diverse entities and individuals in Oregon have either been doing outreach and education (e.g., CRITFC 2019, and USFWS 2019) or are interested in pursuing outreach and education on lampreys. In addition, the Lamprey Technical Workgroup (LTWG 2019) is currently updating BMPs, and its members often discuss survey protocols and provide training workshops on lamprey biology and identification of larval lamprey.

- partner with interested entities and individuals on sharing information about lampreys and providing training
- remain active and engaged in the LTWG.

<u>Approach with ODFW biologists</u>:

Train district and research staff on biology, species identification, monitoring and survey designs to improve the implementation of management strategies and RME. Many biologists know little about the biology of Western River Lamprey, Western Brook Lamprey and Pacific Brook Lamprey. ODFW staff identified the need for BMPs, RME, and an identification guide, along with subsequent training, and data collection protocols for lampreys (Clemens 2017). In addition, training ODFW staff can help them educate citizens and partners on BMPs, and help field staff provide informed comments on permits. The following tactics are examples of what can be implemented:

- update and disseminate existing BMPs periodically, as new information becomes available
- train staff in species identification of lampreys and provide identification guides
- educate and train staff in collection and survey protocols for adult and larval lampreys.

2. Passage and screening

Habitat access was ranked as a key limiting factor for all lampreys in all strata (Table 5.2). Providing passage for lampreys will translate into access to habitats for completion of life cycles and avoidance of low water quality and low water quantity (Table 6.2). ODFW will lead and support work that improves passage and screening throughout Oregon. Existing actions include implementation of policies (see OARs 635-412-0005, 635-412-0035, and 635-500-6060 in Table A10.1) and operation of upstream passage infrastructures (Table A10.2).

<u>Approach</u>:
This strategy consists of existing tactics and ***recommended***, new ones to provide passage and screening (Table 6.2). The following tactics are interconnected examples of what can be implemented:

- continue to provide passage and screening that benefits lampreys (*existing* tactic)
    - tailor passage and screening policies to more directly address lamprey needs (***recommended***, *new* tactic)
        - update passage OARs to accommodate the requirements of adult lampreys as necessary (Tables A10.1 and A10.3) and with information from new RME (Chapter 7)
        - provide guidance on the downstream passage requirements of larvae and juveniles using existing information (Table A10.4) and new information from RME (Chapter 7)

- develop and use protocols to prioritize artificial obstructions for passage and screening improvements (***recommended***, *new* tactic).

3. Protect and restore habitat

Physical habitat was ranked as a key limiting factor for all lampreys in six of seven strata (Table 5.2). Water quality, water quantity, and habitat access are associated with physical habitat. Habitat restoration can address four key limiting factors (Table 6.2):

- *Thwart predation by non-native fishes* by inhibiting their geographical expansion and providing cover for lampreys[16]
- *Improve water quality* through riparian vegetation that shades direct sunlight that can warm the water, stabilizes the input of fine sediment, and filters out pollutants from terrestrial sources
- *Promote water quantity and water quality* through the natural geology and morphology of stream channels to promote connection between ground and surface waters, wetlands and sloughs
- *Improve physical habitat* by restoring natural river processes and channel movements through channel restoration, stocking of large woody debris, and planting of native plants along the channel to promote connection between ground and surface waters, wetlands and sloughs, and the retention of woody debris, other organic materials, and gravel.

Large-scale threats, including climate change, deteriorated estuarine conditions, and increased development are anticipated to exacerbate habitat-related key limiting factors (Chapter 5). Actions that improve habitats should buffer these threats.

Approach:

This strategy consists of existing tactics to protect and restore habitat (Table 6.2). The following tactics extrapolate the approach of ODFW's Coastal Multi-Species Conservation and Management Plan (pp. 82 – 83 in ODFW 2014) to all strata covered in the CPL:

- continue ODFW's Western Oregon Stream Restoration Program, which provides technical expertise to private landowners and Watershed Councils in Western Oregon including restoration of salmonid habitats (used by lampreys)
- work with habitat restoration implementers to complete or update watershed assessments and increase restoration activities in lower mainstem rivers and estuaries that may benefit anadromous lampreys (Homel et al. 2019)
- actively pursue and promote habitat restoration to achieve the goals of lampreys in the CPL and the goals of other native fishes of Oregon (e.g., Table A10.5)

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[16] *The following quote captures the link between habitat and Smallmouth Bass: "*The overriding influence of water temperature on smallmouth bass distribution suggests that managers may be able limit future upstream range expansions of bass into salmon-rearing habitat by concentrating on restoration activities that mitigate climate- or land-use-related stream warming. These management activities could be prioritised to capitalise on survival bottlenecks in the life history of bass and spatially focused on landscape knick points such as high-gradient discontinuities to discourage further upstream movements of bass*" (Lawrence et al. 2012).*

- coordinate with agencies, tribes, landowners, water users, watershed councils, and others to implement habitat protection and restoration activities
- consistent with the Habitat Mitigation Policy (OAR 635-415-0000) and natural ecosystem processes, work to prevent or reduce potential losses of fish production from land and water use actions and habitat alteration to the extent possible, encourage utilization of BMPs for habitat protection when conducting land and water use projects, and promote greater coordination among government partners to facilitate protective measures against climate change and invasive species
- consider and demonstrate preference for alternatives that address natural hazard damage mitigation and restoration of natural disturbance regimes and habitat function when implementing and making recommendations about natural hazard mitigation actions that address hazards such as flooding or fire.

4. Water conservation

Water quantity was ranked as a key limiting factor for all lampreys across all strata (Table 5.2). Climate change and development projections indicate the likelihood of a warmer climate with less surface water and increased demands for that water (Chapter 5). Therefore water quantity will be increasingly important for lampreys and all aquatic life. ODFW has a Water Quality and Quantity Program (https://www.dfw.state.or.us/fish/water/index.asp) that deals with water allocation, water quality, and instream flow protections for fish and wildlife.

Approach:

This strategy consists of existing tactics to conserve water (Table 6.2). ODFW will continue existing programs and strategies (Tables 6.2 and A10.5) to conserve water resources. The following bullets are examples of tactics that can be implemented:

- continue to implement OAR 635-400-0005: "*It is the policy of the Oregon Fish and Wildlife Commission to apply for instream water rights on waterways of the state to conserve, maintain and enhance aquatic and fish life, wildlife, and fish and wildlife habitat to provide optimum recreational and aesthetic benefits for present and future generations of the citizens of this state. The long-term goal of this policy shall be to obtain an instream water right on every waterway exhibiting fish and wildlife values.*" Instream water rights provide target levels for river flows necessary for fishes and their habitats
    - identify areas where lampreys are distributed but do not currently have instream flow protections
    - measure instream flows where necessary
    - identify specifics of instream flow protections for lampreys.
- partner with other agencies and restoration practitioners to implement projects that protect and restore instream flows, especially in flow- and temperature-limited reaches during the summer.

5. Translocation

Translocation is a management strategy that has the potential to establish natural production in locations where a species was historically present (but is currently extirpated). Translocation is an active management strategy some tribes utilize for adult Pacific Lamprey within the Lower

Columbia, Willamette, Mid Columbia, and Lower Snake strata (CRITFC 2011; CRITFC et al. 2018). Portland General Electric has also conducted translocation within the Clackamas River (Ackerman and David 2018). Translocation and its monitoring have become increasingly sophisticated and have shown evidence of successful production of significant numbers of progeny of translocated adults (Ward et al. 2012; Hess et al. 2015; Hess 2016; CRITFC et al. 2018). Translocation should therefore be considered as a strategy for ODFW, in communication with tribes where they are undertaking it and along with supporting actions and RME described in Table 6.3 and Chapter 7, respectively. Translocation can help mitigate limiting factors for Pacific Lamprey in particular strata (Table 6.2) ranked as "limited" to "absent" in current status (Table 3.6)[17]. By transporting adult Pacific Lamprey around limiting factors lower in basins, translocation can:

- re-initiate ecological processes and ecosystem services (Appendix 3),
- minimize predation by pinniped, bird, and non-native fish predators (e.g., as in the mainstem Columbia and Willamette rivers),
- minimize exposure to poor water quality (high water temperatures that are projected to get warmer with regional climate change; Figures A5.2 and A5.9),
- minimize exposure to fluctuating water quantities, and
- mitigate for lack of upstream passage.

Approach:

Translocation is a ***recommended***, new strategy for ODFW to support where on-going by tribes and lead or collaborate on new efforts where warranted. Where appropriate, translocation can be used to reintroduce Pacific Lamprey to spawning and rearing habitats in Oregon where ecological, social, and internal and external institutional capacities and interests align (e.g., Dunham et al. 2016). For example, this could include areas above four major dams in the Willamette stratum: 1) Detroit (North Santiam River), 2) Foster (South Santiam River), 3) Cougar (South Fork McKenzie River), and 4) Lookout Point (Middle Fork Willamette River)[18]. In the Mid Columbia, translocation may be more feasible than providing passage structures to reintroduce lamprey above the Pelton-Round Butte complex (per OAR 635-500-6060; Table A10.1)[19]. In addition, working with tribes, new receiving areas in the Lower Snake stratum may potentially be identified as targets for translocation. Translocation may also be considered along with passage for reintroducing adult Pacific Lamprey into the Upper Snake stratum (Figure 2.10) from which they have been extirpated (Table 2.3). The following bullets are examples of ***recommended***, new tactics that can be implemented by ODFW, tribes or others:

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[17] *In the case of the Upper Willamette population stratum, Pacific Lamprey also have a predicted low probability of occurrence in the mainstem (Table 5.3; Appendix 5, Figure A5.9). This is due in part to excessive water temperatures (Figure A5.2).*

[18] *Portland General Electric already translocates adult Pacific Lamprey above North Fork Dam (Clackamas subbasin) and successfully passes thousands of their larvae and juveniles downstream through a surface collector and associated juvenile migrant pipe.*

[19] *If methods can be found to assist larval and juvenile Pacific Lamprey to escape back downstream through this dam complex (Karchesky et al. 2013).*

- conduct actions supporting translocation (Table 6.3; CRITFC 2011[20])
- identify, prioritize, and conduct translocations into existing and potentially new receiving areas
- use adaptive management to implement best practices based on new information and the best available science.

Table 6.3. Actions ODFW should perform and others (e.g., CRITFC 2011; CRITFC et al. 2018) are already performing, to support ongoing and new adult Pacific Lamprey translocation efforts to increase successful reproduction and outmigration of progeny.

Actions to optimize translocation of adult Pacific Lamprey
– Address limiting factors in the basins receiving adults[21]
– Provide and improve downstream passage and screening to maximize downstream escapement of larval and juvenile Pacific Lamprey
– Monitor genetic population structure and adaptively alter translocation practices to minimize negative genetic effects
– Prevent excessive harvest of donor population(s) of Pacific Lamprey for translocation
– Continue pathogen screening and disease inoculation to prevent translocation of pathogen bearers
– Monitor the success of reproduction of translocated lamprey and adaptively manage translocations to maximize the production of early life stages

6. Establish in-water work Best Management Practices (BMPs)

Knowledge of the existence, timing, and distribution of all lampreys and their life stages in various habitats is essential to minimize impacts on them from in-water work activities (Streif 2009). Adaptation, updating and use of BMPs (USFWS 2010; NRCS 2011; Crandall et al. 2015) is necessary for improving habitat conditions for lampreys and salvaging them.

<u>Approach</u>:

Establishment of in-water work BMPs is a ***recommended***, new strategy for ODFW (Table 6.2) that can inform biologists and managers on optimum seasonal periods for conducting in-water work (dewatering, fish salvage, culvert replacement, habitat restoration, etc.) that can provide

[20] *CRITFC (2011) conducts the following actions to support translocation: 1) uses information from various sources to determine key recipient locations and timing for translocating adult Pacific Lamprey; 2) uses the best available information to determine whether translocation is necessary; 3) considers whether limiting factors have been or are being addressed; 4) adaptively manage translocation to minimize negative effects, including screening for pathogens in prospective donor lamprey; 5) monitor and evaluate translocations, and 6) record and share translocation results.*

[21] *Translocation of adults upstream in the Columbia River Basin may form an ecological sink if limiting factors are not addressed, contributing to the loss of Pacific Lamprey. Limiting factors in the Columbia, such as mainstem passage, tributary passage, and water quality, are acknowledged in CRITFC 2011 and CRITFC et al. 2018. The Federal Columbia River Power River System (FCRPS) is a particular challenge because the progeny of translocated lamprey have difficulty emigrating out to the ocean, and from the ocean back through it. Many larval and juvenile lampreys emigrating through the FCRPS become impinged on traveling screens at each dam and adult migration upstream is severely limited, with few reaching Lower Granite Dam (Figure A6.3). The USACE has been working on a 10-year passage plan for Pacific Lamprey (USACE 2014; CRITFC et al. 2018).*

guidance for when and where to avoid lampreys and how to salvage them. This will address all lampreys across all strata. The following ***recommended***, new tactics are examples of what can be implemented:

- use existing BMPs
- adapt and update existing BMPs with new information.

7. Modify non-native angling regulations

Predation by non-native fishes (Common Carp, Channel Catfish, bullhead catfishes, Walleye, Striped Bass, and Smallmouth Bass) on lampreys (Table A3.4) was ranked as a key limiting factor for all lampreys across the Coastal and Lower Columbia strata, and as a secondary limiting factor for all lampreys across the Willamette and Mid Columbia strata. In addition, these non-native fishes were ranked as an "unknown" factor requiring RME in the Lower Snake and Upper Snake strata (Table 5.2). As previously noted (ODFW 2014) controlling non-native fish predation in rivers where they have become established is currently not possible. However Smallmouth Bass can be controlled where they have recently been introduced and have not yet become established. ODFW will continue to implement existing regulations and ***recommends*** implementation of new regulations to address these concerns (Tables 6.2 and A10.6). Although it seems unlikely that regulatory changes will curb non-native fish populations (e.g., Carey et al. 2011; Loppnow and Venutrelli 2014), the recommended regulation changes can supplement education and outreach about the impacts and geographical expansions of non-native fishes.

Approach:

This strategy is comprised of both existing and ***recommended***, new tactics designed to control and inhibit the geographical expansion of non-native fishes that prey on lampreys. The following tactics are examples of what can be implemented:

- aggressively contain and control new, non-sanctioned introductions of non-native fishes to prevent their establishment and expansions (*existing* strategy)
- prohibit introduction of non-native fishes into flowing waters through the continuation and enforcement of fish transportation permit requirements (OARs 635-007-0600 through 635-007-0625; *existing* strategy)
- maintain or modify harvest regulations to remove bag and size limits for Smallmouth Bass, catfishes (Channel Catfish and bullhead catfishes), Walleye, and other non-native fishes (Table A10.6; *existing* and ***recommended***, *new* strategy).

8. Pinniped management

ODFW has recently gained federal approval to euthanize California Sea Lions (CSL) at Willamette Falls to protect salmon and steelhead. Although this strategy is new, it will be an existing strategy by the time the CPL is formally adopted. This action should also benefit adult Pacific Lamprey and Western River Lamprey (Table 6.2).

Approach:

Continue to implement this strategy.

OTHER MANAGEMENT STRATEGIES

Direct human interactions (i.e., release and take) are not currently recognized as limiting factors (Chapter 5), but have the potential to become limiting factors in the future. Competition, disease, genetic effects of released hatchery lamprey and translocated lamprey are not limiting factors; however the extent and impacts of these factors on lampreys is unknown and warrants investigation and caution (see Chapter 5 and Chapter 7). Examples of new tactics that can be implemented for releases of hatchery Pacific Lamprey include:

- monitor the presence of hatchery Pacific Lamprey into release areas in Oregon
- communicate with tribes to learn details about the releases
- inform ODFW permit reviews for potential impacts from water use, screens and passage, and in-water work in the Walla Walla River (Mid Columbia stratum) and potentially other new release areas in the future.

Examples of existing and new tactics for scientific take that can be implemented include:

- ODFW will continue to monitor and comment on scientific take applications using the information in the CPL as a guide
- ODFW will monitor and evaluate areas of potentially excessive scientific take, such as Pacific Lamprey within the Coastal stratum (Chapters 5 and 7)
- provide lamprey identification guides for scientific take permits where lamprey bycatch is likely

Harvest of lampreys is not identified as a limiting factor. However, ODFW manages harvest of fishes, including lampreys, by statutory (ORS 506.036; ORS 506.109) and administrative rules (OAR 635-007-0502 and Table A10.1) in fulfillment of its mission, "*To protect and enhance Oregon's fish and wildlife and their habitats for use and enjoyment by present and future generations.*" Most personal use harvest occurs at Willamette Falls (Figure A8.1; Table A8.4), which is regulated by OAR 635-017-0080 (Table A10.1). Currently the harvest of adult Pacific Lamprey at Willamette Falls is managed by season dates (June 1 – July 31) and daily harvest hours (7:00 AM – 6:00 PM) without a daily or seasonal bag limit. Harvesters are required to have a personal use permit and to fill out the number of lamprey harvested on a harvest card that they return to ODFW. Willamette Falls remains an important location for tribal harvest to support traditional uses (ceremonial and subsistence needs), and is one of the few remaining locations where the relative abundance of adult Pacific Lamprey still supports harvest. Oregon Department of Fish and Wildlife staff compile data on the number of harvested lamprey from all returned harvest cards and enters this data into a spreadsheet to generate year-by-year tallies of harvest at Willamette Falls.

CONCLUSIONS

This chapter presented eight management strategies for lampreys to address their key limiting factors and complex, large-scale threats. An adaptive approach will be necessary to implement new information and the best available science to improve these management strategies. The efficacy of these strategies to address limiting factors and threats to lampreys is not yet known. These limiting factors and threats may worsen and new factors and threats may arise in the future. Deliberate and consistent efforts, funding, and coordination among entities will be necessary to carry out management strategies to offset additional impacts of complex, large-scale threats. Chapter 7 discusses RME to address unknowns pertaining to limiting factors and threats.

Chapter 7: Research, monitoring, and evaluation

Research, monitoring, and evaluation categories were identified to address key unknowns relative to limiting factors and threats to lampreys (Table 7.1). These RME are: tied to specific management strategies, tractable, feasible, adaptive, and provide relevant and significant feedback relative to effort. Identified RME can provide a framework for assessing the status of lampreys and the limiting factors and threats to them (Table 7.2). These RME can enable evaluation of management strategy effectiveness and inform how these strategies can be adaptive (Table 7.3). These RME were prioritized by the relative input each is estimated to provide for filling key information gaps for lampreys. RME were prioritized through several considerations (Table 7.1). For each RME these considerations were ranked “Low” (score = 1), “Varies” (1), “Moderate” (3) or “High” (4), and then summed to determine priority (Table 7.1). “Importance to management strategies” was weighted two times greater than the other considerations. Tied scores were ordered by professional judgment. Implementation will require continuation of existing RME, implementation of new RME (Tables 7.1 and 7.2), and support of other on-going RME. The following describes each RME.

1. Improve distribution information

Occurrence and distribution modeling for lampreys is an important RME need (Kostow 2002; Clemens et al. 2017a). Distribution data is lacking for Pacific Lamprey and Western Brook Lamprey in the Rogue/South Coast and Willamette population strata and strata east of the Cascades (Figures 2.6 – 2.10; Table 3.2). Distribution data is lacking for Western River Lamprey and Pacific Brook Lamprey throughout Oregon. In addition, standardized survey protocols for lampreys are needed (Clemens et al. 2017a).

<u>Approach</u>:

ODFW will work with partners to build on existing distribution information for lampreys (Table 7.4). The following bullets are examples of RME ***recommended*** for implementation.

- increase the extent of spatial and temporal sampling to improve the predictive power of SDMs
- include surveys into population strata that are beyond the known distribution of a particular lamprey species
- augment existing spatial data with metadata and biological data
- create and curate a centralized database using existing data and the existing ODFW distribution database. The database will contain high-quality data that is integrated for analyses of status and trends of lampreys[22]
- synthesize data to generate up-to-date maps for all lampreys
- compare survey methods for lampreys and provide recommendations for standard protocols for future surveys
- collaborate and coordinate data collections and procedural recommendations with partners who have conducted, are conducting or will conduct distribution surveys for lampreys.

[22] *ODFW shares new distribution information for Pacific Lamprey with the USFWS for use in their distribution mapping in the PLCI.*

Table 7.1. Research, monitoring, and evaluation strategies (left column) to address key unknowns for lampreys. These were ranked from high to low priority (top to bottom) for the relative impact to informing management strategies based upon 11 considerations represented in columns.

	Addresses multiple species	Addresses multiple life stages	Addresses multiple population strata	Addresses unknowns	Management applicability	Importance to management strategies	Integration to other RME	Enables status assessment	Informs limiting factors, threats	Feasibility	Information gain relative to effort
Improve distribution info.	High	High	High	High	High	High	High	High	Moderate	High	High
Prioritize passage & screening	High	High	High	High	High	High	High	Varies	Moderate	High	High
Inform passage & screening	High	High	High	High	High	High	High	Moderate	High	Varies	High
Improve biological knowledge	High	High	High	High	High	High	High	Moderate	High	Varies	Moderate
Estimate take	High	High	High	High	High	High	High	Low	Moderate	High	Moderate
Assess complex, large-scale threats	High	High	High	Moderate	High	Moderate	High	Low	High	High	High
Assess translocation [a]	Low	High	Moderate	High	High	High	High	Low	High	Moderate	High
Estimate adult abundance	Low	Moderate	High	High	High	High	High	High	Low	Low	Low
Monitor diversity	High	Moderate	High	Moderate	Moderate	Moderate	High	Varies	Low	Low	Varies

[a] Analyses designed to assess and optimize the effectiveness of translocations (per Table 6.3).

Table 7.2. Nine research, monitoring, and evaluation (RME) strategies (top row, arranged from left per Table 7.1) to address key unknowns for lampreys with regards to limiting factors and complex, large-scale threats (left column). Strategies are for all lampreys unless indicated otherwise. In the top row, "new" = novel RME for ODFW; "existing" = RME already being employed by ODFW. The population strata (PS) include: RSC = Rogue/South Coast; CST = Coastal; LC = Lower Columbia; WI = Willamette; MC = Mid Columbia; LS = Lower Snake and US = Upper Snake.

<table>
<tr><th></th><th>Improve distribution information (New & Existing)</th><th>Prioritize passage & screening (New)</th><th>Inform passage & screening (New)</th><th>Improve biological knowledge (New)</th><th>Estimate take (New & Existing)</th><th>Assess complex, large-scale threats (New)</th><th>Assess translocation (New & Existing)</th><th>Estimate adult abundance (New & Existing)</th><th>Monitor diversity (New)</th></tr>
<tr><td>Take</td><td rowspan="7">Addresses all unknowns (all PS)</td><td rowspan="4"></td><td rowspan="4"></td><td rowspan="7">Addresses all unknowns (all PS)</td><td>Addresses take (all PS)</td><td rowspan="7">Addresses all unknowns (all PS)</td><td rowspan="5">Addresses unknowns pertaining to take, predation, and habitat for Pacific Lamprey (LC, WI, MC, LS, & US)</td><td rowspan="5">Addresses unknowns pertaining to take, predation, and habitat for Pacific Lamprey (all PS)</td><td>Addresses unknowns pertaining to within-species diversity and take (all PS)</td></tr>
<tr><td>Other Species</td><td></td><td></td></tr>
<tr><td>Water Quality</td><td rowspan="3">Addresses unknowns pertaining to habitat (all PS)</td><td rowspan="3">Addresses unknowns pertaining to within-species diversity and habitat (all PS)</td></tr>
<tr><td>Water Quantity</td></tr>
<tr><td>Habitat Access</td><td>Addresses unknowns pertaining to passage (all PS)</td><td>Addresses unknowns pertaining to passage (all PS)</td></tr>
<tr><td>Physical Habitat</td><td rowspan="2"></td><td rowspan="2"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Climate Change; Develop-ment</td><td>Addresses relative abundance relative to climate (all PS)</td><td>Addresses Pacific Lamprey abundance relative to climate (LC, WI, MC, LS, & US)</td><td>Addresses Pacific Lamprey abundance relative to climate (all PS)</td><td>Addresses within-species diversity relative to climate (all PS)</td></tr>
</table>

Table 7.3. Relationships between RME (left column, arranged top to bottom per Table 7.1) and management strategies (top row; arranged left to right per Table 6.2).

<table>
<tr><th></th><th>Education & outreach</th><th>Passage & screening</th><th>Protect & restore habitat</th><th>Water conservation</th><th>Translocation</th><th>In-water work BMPs</th><th>Implement non-native regulations</th><th>Pinniped management</th></tr>
<tr><td>Improve distribution information</td><td colspan="4">Informs gaps in education, passage & screening and habitat use</td><td colspan="2">Informs presence/absence</td><td colspan="2"></td></tr>
<tr><td>Prioritize passage & screening</td><td colspan="4">Informs outreach, where passage & screening can be implemented, and restored habitats can be accessed</td><td>Addresses passage & screening needs for progeny of translocated adults</td><td colspan="3"></td></tr>
<tr><td>Assess complex, large-scale threats</td><td colspan="4">Informs education & outreach, passage & screening, and habitat needs relative to threats</td><td colspan="2">Informs adaptive management of translocation and variability of in-water timing of lampreys</td><td colspan="2"></td></tr>
<tr><td>Inform passage & screening requirements</td><td colspan="2">Informs practitioners</td><td colspan="2"></td><td>Informs passage requirements for progeny of translocated adults</td><td colspan="3"></td></tr>
<tr><td>Improve biological knowledge</td><td colspan="7">Informs all aspects of education & outreach, passage & screening, habitat restoration, water conservation, harvest, translocation, in-water timing of lampreys, and predation on them</td><td></td></tr>
<tr><td>Estimate take</td><td>Informs collectors, harvesters, and public</td><td colspan="3"></td><td>Informs translocation (and vice versa)</td><td colspan="3"></td></tr>
<tr><td>Estimate adult abundance</td><td colspan="2">Informs tribes, stakeholders, and general public, and informs potential effectiveness of passage & screening fixes</td><td></td><td colspan="2">Determines potential relationship between water availability and abundance, harvest and abundance, and translocation practices and abundance</td><td colspan="3"></td></tr>
<tr><td>Assess translocation</td><td colspan="3">Provides information about translocation effectiveness and informs potential passage & screening needs for the progeny of translocated adults. Also informs habitat restoration and water needs in receiving areas</td><td></td><td>Informs effectiveness and adaptive management of translocation</td><td colspan="3"></td></tr>
<tr><td>Monitor diversity</td><td>Informs education and outreach</td><td colspan="2"></td><td colspan="2">Determines potential relationship between water availability and diversity. Informs harvest regulations and translocation actions with respect to within-species diversity</td><td colspan="3"></td></tr>
</table>

Table 7.4. Relative density of distribution data by population stratum and lamprey species. Cells with an "X" indicate relatively rich datasets (but not necessarily thorough and balanced sampling efforts in space and time). Cells with an asterisk indicate very little to no data. NA = not applicable (extirpated).

Population stratum	Pacific Lamprey	Western River Lamprey	Western Brook Lamprey	Pacific Brook Lamprey
Rogue/South Coast	*	*	*	*
Coastal	X	*	X	*
Lower Columbia	X	*	X	*
Willamette	X	*	*	*
Mid Columbia	*	*	*	*
Lower Snake	*	*	*	*
Upper Snake	NA	*	*	*

2. Prioritize artificial obstructions for passage and screening

This ***recommended*** new RME is closely associated with management strategy #2, "provide passage and screening" (Table 7.3).

<u>Approach</u>:

Prioritize artificial obstructions for providing upstream and downstream passage and screening for lampreys. The following bullets are examples of RME that can be implemented:

- Determine the number, location, and type of artificial obstructions throughout Oregon
  - gather data from existing barrier databases
  - augment the barrier database(s) with the amount of habitat above artificial obstructions
  - augment the barrier database(s) with the distance between each artificial obstruction and the ocean.

3. Inform passage and screening requirements

Passage requirements for lampreys have focused on the adult life stage of Pacific Lamprey at large hydropower dams in the Columbia and Snake rivers (e.g., Moser and Mesa 2009; Keefer et al. 2009a, 2010, 2012, 2013; Moser et al. 2015a; PLTWG 2017). Research is needed to fill information gaps in other areas:

- *Larvae and juveniles*. Downstream passage requirements for these early life stages are essential to inform dam retrofits and restructuring to provide passage. For example, retrofits or restructuring may be necessary to enable successful reintroduction of Pacific Lamprey above Pelton-Round Butte complex in the Deschutes River (OAR 635-500-6060; Table A10.1) [6, 17].
- *Adult Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey*. Although these species overlap in distribution, one might assume passage differences based upon differences in adult body size (and thus climbing/swimming ability). The following quote captures the lack of knowledge for Western Brook Lamprey and Pacific Brook Lamprey; it also pertains to the "non-brook" species, Western River Lamprey: "…*research on the spawning migrations of the strictly potamodromous species (….the non-parasitic 'brook' lampreys) is sorely lacking, seriously compromising our ability to assess what constitutes barriers to their*

migration" (Moser et al. 2015b). In addition, as ODFW staff noted, "*Passage OAR criteria for lampreys may need to be revisited as it may not be sufficiently and effectively detailed/prescriptive to be useful for managers, biologists, and especially lamprey*" (Clemens 2017)

- *Different types of artificial obstructions*. Although lacking empirical data, it has been hypothesized that using natural stream beds within culverts may improve lamprey passage through these culverts (Clemens et al. 2017a). No information exists for passage behavior, constraints or needs of adults, larvae, or juvenile lampreys at tide gates. Passage efficiency and requirements at various screens and diversions (e.g., farmer screens, rotary drum screens, push-up diversions, and pump and gravity diversions) are not currently known

Approach:

This ***recommended*** new RME will fill information on passage requirements for all lamprey species, life stages, and types of artificial obstructions (Table 7.2). The following bullets are examples of tactics that can be implemented:

- improve understanding of adult lamprey passage behavior and requirements at various types and sizes of artificial obstructions.
- improve understanding of upstream passage conversion factors for the proportions of adult Pacific Lamprey between mainstem dams in the Columbia River.
- work with partners to conduct controlled laboratory experiments to test the passage efficiencies of all life stages of Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey across a range of temperatures, hydraulics, screens, and types of artificial obstructions, with the goal of realizing significant improvements in lamprey passage
- work with partners to conduct field experiments to test the passage of larvae and juveniles of all lampreys and adults of Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey across a range of temperatures, hydraulics, screens, and types of artificial obstructions, to improve the understanding of passage requirements
- work with tribes and other partners to evaluate effective means to provide downstream passage and screening for larval and juvenile Pacific Lamprey through the artificial barriers over which their progenitors were translocated
    - host a workshop among scientists and engineers from various entities and sub-disciplines to generate novel, testable ideas to minimize or prevent entrainment and impingement of larval and juvenile lamprey at artificial barriers. Create and disseminate written proceedings and recommendations of the workshop
- formulate passage requirements for larval and juveniles of all lampreys and adults of Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey across species and types of artificial obstructions.

4. Improve knowledge of biology

The need for research on the biology, ecology, and habitat needs for Pacific Lamprey, Western River Lamprey, and Western Brook Lamprey has been identified by others (Kostow 2002; Meeuwig et al. 2004; USFWS 2004). Work to improve knowledge of biology of lampreys is fundamental to addressing all aspects of all measurable criteria, limiting factors and threats (Table 7.2), and it includes all categories of RME.

Approach:

Although ODFW has contributed to the scientific knowledge of lamprey biology (e.g., Kostow 2002; Gunckel et al. 2009; Starcevich et al. 2014), this ***recommended*** RME is largely new for ODFW (Table 7.2). Additional research and monitoring on life cycle timing, ecology, habitat use, and biology is recommended for all lampreys (e.g., Tables 2.1 – 2.2), from a wide-range of watersheds to inform passage and screening, habitat needs, in-water work BMPs, etc. (Table 7.3). The following bullets are examples of RME (presented in order of importance) that can be implemented:

- partner with others to assess the effects of toxins on lampreys (e.g., the Water Quality Pesticide Management Team via the Pesticide Stewardship Partnership, which was described in Chapter 5)
- work with partners to conduct laboratory experiments and field research to address questions relative to habitat use for all lampreys
- work with partners to conduct exploratory field research to describe the ecology and biology of lampreys relative to habitat use across space and time in a wide variety of habitats within various strata for all lamprey species.
- Work with partners to support studies on the effects of toxic pollutants on lampreys.
- Work with partners to support studies on the prevalence of toxic pollutants in the environment and in lamprey tissues.

5. Estimate take

Take includes harvest, translocations from one location to benefit a receiving location, broodstock collection for hatchery programs, scientific collection, and other uses.

- Although annual harvest numbers are believed to be accurately assessed, lack of information on harvest rates and sustainable harvest levels leads to uncertainty about harvest management strategies at Willamette Falls. This RME addresses key unknowns with respect to the proportion of harvest from the population(s) at-large for adult Pacific Lamprey at Willamette Falls (Tables 5.2 and 7.2).
- Numbers of adult Pacific Lamprey collected for translocation are generally known. The tribal Master Plan (CRITFC et al. 2018) recently detailed numbers of adult Pacific Lamprey translocated during 2000 – 2016 collection years. An unknown number of adult Pacific Lamprey collected during translocation operations are used as broodstock for hatchery operations.
- The numbers of fish taken for scientific purposes is known (Tables A8.4 & A8.5) and the immediate effects of this type of take is assumed to be minimal (Chapter 5). However, the overall impact from scientific take within populations and across years has not been directly assessed.

Approach:

Take in all forms (harvest, translocation, broodstock collection, and scientific collection) is an unknown limiting factor (Table 5.2) that warrants further documentation and subsequent assessment. The following bullets are examples of tactics that can be implemented:

- estimate the harvest rates of adult Pacific Lamprey at Willamette Falls (Willamette stratum)
    - continue existing procedures of recording and tallying reported harvest
    - Initiate or support creel surveys done by tribes to supplement reported harvest
    - use harvest data along with information from RME #8 (Estimate adult abundance) to estimate the rate of harvest
- assess the impact of non-harvest take on local populations of lampreys
    - conduct studies to better understand lamprey population structure and dynamics, including distribution (RME #1), abundance (RME #8), and genetic (RME #7, #9) information
    - continue working with tribes to track numbers of adult Pacific Lamprey collected from particular locations and released elsewhere or used for broodstock.
    - continue to record and track scientific take
    - identify population-specific take and assess take rates and impact to populations

6. Assess complex, large-scale threats

ODFW has begun analyses of complex threats (e.g., distribution modelling in chapter 3 and 5, Appendix 5, and contingency tables in Appendix 9). Otherwise this category of RME is ***recommended*** RME for ODFW (Table 7.2).

Approach:

Collaborate with and support partners in distribution modelling of lampreys in relation to complex, large-scale threats. The following bullets are examples of tactics that can be implemented:

- using new information from RME #1, "improve distribution information" along with existing distribution information (Figures 3.1 and A5.9; Table 5.3), refine SDM predictions for key environmental variables affected by climate change on the distribution of lampreys (measurable criterion 6a; Table 3.1)
- collaborate with partners to predict the impacts of increases in human population in Oregon, and the impacts of expanding urban and infrastructural development on lamprey habitats and lamprey distribution
    - analyze available data to predict the impacts of increases in human population, urbanization, and infrastructure on water quality, water quantity, habitat access, physical habitat, and lamprey distribution
- collaborate with and support partners in RME on Pacific Lamprey and Western River Lamprey in the ocean
    - collaborate with and support partners in information sharing and field and laboratory research.

7. Assess translocation

Translocation is an existing management strategy for various tribes (see Chapter 5) and it is a new management strategy for ODFW (see Chapter 6). This RME is ***recommended*** and addresses the ongoing need to monitor, assess, and optimize the effectiveness of this management strategy (Table 6.3) for Pacific Lamprey in five strata (Table 7.2).

Approach:

Use RME to optimize translocation (Table 6.3). The following bullets are examples of tactics that can be implemented:

- work with tribes and other partners to evaluate whether limiting factors in basins designated to receive adults have been or are being adequately addressed (Table 5.2)
- work with tribes and other partners to monitor and evaluate the genetic population structure of donor and recipient population(s) of Pacific Lamprey
- where not in place, work with tribes and other partners to determine a sustainable number of adult Pacific Lamprey to take for translocation from specific donor populations or locations
    - work with tribes and other partners to enumerate and parse genetic stock structure into numbers of lamprey, per dam, per year
    - work with tribes and other partners to evaluate data to assess a sustainable amount of take for translocation from the donor population(s)
- work with tribes and other partners to screen for pathogens and conduct translocations in a manner that reduces transmission of disease
- work with tribes and other partners to monitor the reproductive success of translocated lamprey.

8. Estimate adult abundance

"…*we lack the necessary information to assess the affects* (sic) *of the* [Pacific Lamprey] *harvest* [at Willamette Falls] *on the population*" (Kostow 2002)

This RME focuses on Pacific Lamprey and addresses measurable criterion 6b ("Adult abundance trends"; Table 3.1). Estimates of adult abundance are currently needed in all strata except for the Upper Snake, where they are currently extirpated (Table 3.6). Adult abundance estimates, along with other biological and environmental variables previously identified (e.g., Murauskas et al. 2013; Sharma et al. 2016) can enable prediction of run sizes, which are necessary to understand relative abundance and inform harvest regulations and translocation. Abundance is a general area of RME needs (Kostow 2002; Clemens et al. 2017a). Statistical model(s) are needed to predict the relative abundance of Pacific Lamprey at key locations for translocation (i.e., the mainstem dams on the Columbia River), and at a key source for tribal harvest — Willamette Falls (Willamette stratum).

Approach:

Continue, re-initiate, or start ***recommended*** new RME to estimate the abundance of adult Pacific Lamprey in six strata from now into the future (Tables 7.2 **–** 7.3). The following bullets are some examples of what can be implemented:

- continue existing RME (Table 7.5)
- re-initiate Pacific Lamprey spawning ground surveys in the Rogue/South Coast stratum (Table 7.5)
- begin new task of counting adult Pacific Lamprey in the fish ladder at Willamette Falls (Table 7.5)
- using existing data (Appendix 6) and future data, create statistical models to predict the historical and future abundance of adult Pacific Lamprey
- use the information from the bullets above to inform management strategies (Table 7.3).

Table 7.5. Comparison of data sources for abundance of adult Pacific Lamprey across population strata, with proposed future RME (indicated in **bold**). An inventory of data sources can be found in Tables A6.1 – A6.2. NA = not applicable ("absent"). – = no data.

Population stratum	Spawning ground surveys	Dam counts	Mark/recapture estimates [a]	Notes	Proposed RME [b]
Rogue/South Coast	**OASIS**	–	–	SGS occurred prior to 2015 and since have been discontinued	***Re-initiate* SGS**
Coastal	OASIS	Winchester Dam	–	–	Continue both SGS and dam counts
Lower Columbia	OASIS	Bonneville Dam	Willamette Falls	–	Continue SGS
Willamette	OASIS	**Willamette Falls (*New*)**	Willamette Falls	SGS occurred in 2016 – 2017 and have re-initiated in 2018	Continue SGS **Begin counting adult Pacific Lamprey at fish ladder** [c]
Mid Columbia	–	Individual dams listed in Table A6.2	Cushing Falls; Sherars Falls	–	Support mark/recapture estimates (Table A6.2)
Lower Snake	–	Individual dams listed in Table A6.2	–	–	–
Upper Snake	NA	NA	NA	–	–

[a] Conducted by the Confederated Tribe of the Warm Springs Reservation of Oregon (see Table A6.2 for details).

[b] Contingent upon staff and funding availability.

[c] Begin with an evaluation of efficacy by calibrating with other research data, as possible.

9. Monitor diversity

Diversity is a general area of RME needs (Kostow 2002; Clemens et al. 2017a). This RME is ***recommended*** and new for ODFW (Table 7.2) and it addresses the measurable criterion, "within and among population diversity" (measurable criterion 6c; Table 3.1).

Approach:

Build on existing information (Appendix 3) to describe the genetic and phenotypic diversity of lampreys throughout Oregon. The following bullets are examples of tactics that can be implemented:

- document genetic and phenotypic diversity[23] by creating and executing study designs for sampling genetic and phenotypic information for all lamprey species
- compare the genetic and phenotypic diversity relative to estimates of adult abundance (RME #7) and environmental variables such as river flows to discern potential patterns in the dynamics of population(s) of Pacific Lamprey.

CONCLUSIONS

This chapter presented nine RME strategies to address the key unknowns, limiting factors, and complex, large-scale threats identified in Chapter 5. Challenges remain to carrying out these RME include the potential worsening of existing limiting factors and threats at rates faster than RME can fill-in information gaps. Chapter 8 discusses how the nine management strategies and nine RME can be implemented.

[23] *Non-lethal fin clip for genetic analyses and record total body length (mm), date, river, GPS coordinates, and take a photograph of the fish against a measuring board background.*

Chapter 8: Implementation

This chapter details what is necessary to implement the CPL and achieve desired status for Pacific Lamprey, Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey throughout Oregon. ODFW is responsible for implementing the CPL to achieve desired status for lampreys (Chapter 4). The key pieces of the CPL that require implementation are the management strategies (Chapter 6), RME (Chapter 7), and overarching implementation requirements (this chapter). To achieve this implementation, ODFW is committed to:

- implementing actions over which it has direct authority
- continuing its involvement in other plans that have actions that benefit lampreys (Table A10.5), and
- working cooperatively and using creative partnerships with all interested entities and individuals to implement education and outreach, direct management, RME, voluntary habitat restoration, and pro-active habitat protection projects.

ODFW's Statewide Lamprey Coordinator will lead in implementing the CPL, coordinating specific needs for management strategies and RME with other ODFW staff in districts and programs, and with other persons and entities.

COLLABORATION

Many of the management strategies and RME called for in the CPL are ambitious and ODFW does not have the capacity to execute these alone. Therefore, identifying, acknowledging, and supporting actions already being undertaken by tribes and other partners interested in conservation of lampreys, and fostering continued and improved collaborations with them, will be essential to implementing the management strategies and RME called for in this plan. Numerous actions have occurred and are occurring by tribes, the USFWS, and other entities to benefit Pacific Lamprey across their range and in Oregon (Table 1.2; CRITFC 2011; Luzier et al. 2011; USFWS 2018). Opportunities may exist to collaborate, and either build upon existing or initiate new efforts, to benefit Pacific Lamprey and their habitats. Some of these strategies and RME will benefit other lampreys and shed light on their biology. Opportunities also exist for creative solutions and innovative collaborations to benefit Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey.

TIMELINE

Most of the management strategies and RME can begin in the near term and continue into the long term as on-going work or until completed (Table 8.1). Several management strategies should be completed in the near term (Table 8.1). Some RME will also inform specific management strategies (Table 7.3). Details of anticipated near term implementation (i.e., over the next five years) are provided in Appendix 11. Intermediate and long term implementation will depend on the results of near term implementation, funding, and partnership opportunities.

Table 8.1. Estimated schedule for implementation of management strategies and RME identified in Tables 6.2 and 7.2, respectively. X = implementation.

Management strategies	Near term *(0-5 yrs)*	Intermediate term *(5-10 yrs)*	Long term *(10-20 yrs)*
Education and outreach	X	X	X
Provide passage & screening [a]	X	X	X
Protect & restore habitat [a]	X	X	X
Water conservation [a]	X	X	X
Translocation [a]	X	X	X
Establish in-water work BMPs	X		
Implement angling regulations on non-native fishes	X		
Pinniped management	X	X	X
RME			
Improve distribution info. [a]	X	X	X
Prioritize passage & screening	X	X	X
Inform passage & screening requirements [a]	X	X	X
Improve knowledge of biology [a]	X	X	X
Estimate take [a]	X	X	X
Assess threats	X	X	X
Assess translocation [a]	X	X	X
Estimate adult abundance [a]	X	X	X
Monitor diversity [a]	X	X	X

[a] Partially or completely dependent upon procurement of external funds or partner contributions.

COST

Some of the management strategies and RME contained in the CPL can be completed by continuing existing efforts or leveraging existing staff and funds. These will not require additional funding (Table 8.1). However, if ODFW funding is reduced or staff are re-prioritized, this work may slow or not be able to be completed.

Additional funding or significant partner contributions (in terms of conducting or collaborating on projects) will be needed for implementation of other management strategies and RME (Table 8.1). In these cases, ODFW will pursue external funding or coordinate and collaborate with partners to implement these actions. Successful implementation will be dependent upon the availability of funding, successful partnerships, or the independent completion of projects by other entities.

REPORTING, ADAPTIVE MANAGEMENT AND RE-ASSESSMENT

Information related to implementing the CPL will be aggregated, reported, and posted in a publicly-accessible ODFW website as available. If information appears to show that progress is not being made towards desired status goals or some population strata are declining to critical abundance levels, ODFW will consider if additional or alternative management strategies or actions need to be implemented (and identify what those actions will be) to change the trajectory. Data will also be used to adjust harvest and other forms of take, or modify actions called for in the plan, as necessary.

The total life span for Pacific Lamprey averages about 9 yrs (range: 4 – 13 yrs; Clemens et al. 2017a). A re-evaluation of the status of lampreys will be done in 2040 with data on hand. This roughly coincides with two lamprey generations after CPL implementation begins (2 generations X 9 years per generation = 18 years) and coincides with the 2040 future projections identified in this plan for probability of occurrence of lampreys (Chapter 5). If this status re-assessment shows that progress is *not* being made towards desired status goals, including strata exhibiting steep declines or further declines towards critical abundance levels, ODFW will consider additional or alternative strategies to change the trajectory of particular lamprey species in particular strata. If the status or goals of the population stratum and strategies to achieve desired status need to be substantively changed or modified as a result of this broader re-assessment, a public process will be undertaken, with OFWC approval necessary for such changes. Review of the CPL will be required if any Pacific Lamprey, Western River Lamprey, Western Brook Lamprey, or Pacific Brook Lamprey stratum becomes listed under the federal ESA or if a future status assessment determines a currently viable population stratum has become non-viable.

OUTCOMES

The desired outcomes for lampreys addressed in the CPL are described in Chapter 4. In addition to the beneficial outcomes for these species, implementation of the CPL is expected to have other beneficial outcomes.

Other native fishes and ecosystem benefits

"*The recovery of Pacific lamprey may be linked to salmon recovery*" (Close et al. 1995).

Oregon lampreys have co-existed with native fishes of Oregon for thousands of years. Appendix 3 discusses the relationships of lampreys to other fishes. The vision of the CPL is to combine strategies and RME targeted towards lamprey with habitat protection and restoration that benefits lampreys and other native fishes.

The presence of Pacific Lamprey may be an indicator of ecosystem health (Close et al. 1995). The same is likely true for the presence of Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey in environments. Healthy populations of lampreys are a key component of freshwater ecosystems, including as sources of prey for many different fish, bird, and mammal predators (Table A3.4). Lampreys may also serve as predation buffers for listed salmonids (Close et al. 2002). Anadromous lampreys contribute marine-derived nutrients to freshwater ecosystems. Larval lamprey move and aerate stream beds, creating micro habitats that subsequently become occupied by aquatic insects that juvenile salmonids prey upon[24]. Thus lampreys are important to the ecological functions of ecosystems in Oregon that produce other native fishes and wildlife.

Cultural benefits

Pacific Lamprey provide foodstuffs, medicine, and ceremonial benefits to Native American tribes (Chapter 1). Declining numbers of Pacific Lamprey have raised concerns for reduced harvest opportunities for tribes (Close et al. 2002; CRITFC 2011; Sheoships 2014). Actions undertaken to stem declines and improve lamprey numbers may assist with cultural awareness and potentially improve harvest opportunities. Ethically, lampreys are worth conserving because of

[24] *Details on ecosystem benefits are provided in Appendix 3.*

their intrinsic value. Lampreys have been model organisms for developmental, anatomical, and medicinal researchers (Docker et al. 2015).

OUTLOOK

The CPL is intended to increase awareness and understanding of the biology of lampreys, their statuses, limiting factors, management needs, and information gaps. This plan is intended to provide a framework for increasing knowledge that can improve management certainty for lampreys. The CPL will be a living document that evolves as more is learned about lampreys and the effectiveness of management strategies are assessed and adapted. The goal of the CPL is to improve lamprey status. Improved status of lampreys can increase their social and cultural benefits for Oregonians, and strengthen the ecological connections that lampreys provide to ecosystems. Because uncertainty exists for the statuses of lampreys and the strategies necessary to improve these, it is important to observe how the actions called for in the CPL work and how lampreys respond. Re-assessment of the status of Pacific Lamprey, Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey will occur in the year 2040 (approximately two generations in the future).

The desired status for each lamprey species is ambitious, and achieving it will require significant improvements in limiting factors (Table 5.2) and threats (Tables A9.1 – A9.2) that lampreys face. To address these, a concerted effort will be needed by ODFW and partners to implement lamprey management strategies, as well as actions in other plans that benefit lamprey habitats and access to those habitats (Table A10.5). Although expected to make significant improvements, the management strategies identified in the CPL are not *guaranteed* to improve the status of lampreys, because specific limiting factors or threats may be significantly more important than currently believed or may be changing faster than realized. Similarly, threats outside the scope of ODFW's management ability, such as ocean conditions, may have a more significant impact to anadromous lampreys (Pacific Lamprey and Western River Lamprey) than the inland management strategies identified in the CPL. The identified need to monitor the effects of climate change, estuarine and ocean conditions, and development relative to human population growth on factors limiting lampreys and the additional vigilance called for in the RME chapter relative to carrying out management strategies, should serve to allow adaptive management to address and offset these future threats.

Ultimately, implementation will require dedicated, productive collaborations with all parties interested in lamprey conservation, concerted efforts, and vigilant RME. This combination should ensure the conservation of the lamprey species addressed in this plan into the future.

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Acronyms and abbreviations

BiOp...................... Biological Opinion
BMP .... Best Management Practice
Cfs......................... Cubic feet per second
CPL .... Coastal, Columbia, and Snake Conservation Plan for Lampreys (i.e., this plan)
CRITFC .... Columbia River Inter-Tribal Fish Commission
CST .... Coastal population stratum (ODFW)
CTGR .... Confederated Tribes of Grand Ronde
CTUIR .... Confederated Tribes of the Umatilla Indian Reservation
CTWSRO .... Confederated Tribes of Warm Springs Reservation of Oregon
DSL .... Department of State Lands
e.g. .... for example
FCRPS .... Federal Columbia River Power System
Fps .... feet per second
Ft .... foot/feet
HUC....................... Hydrologic Unit Code
i.e. .... that is
In .... inches
LC.......................... Lower Columbia population stratum (ODFW)
LPS .... Lamprey Passage Structures
LS.......................... Lower Snake population stratum (ODFW)
LTWG.................... Lamprey Technical Workgroup
MC......................... Middle Columbia population stratum (ODFW)
Mi .... miles
Mos .... months
NMFS .... National Marine Fisheries Service
NOAA.................... National Oceanic and Atmospheric Administration
NWPCC................. Northwest Power and Conservation Council
OAHP .... Oregon Agricultural Heritage Program
OAR .... Oregon Administrative Rule
OASIS .... Oregon Adult Salmonid Inventory and Sampling (ODFW)
ODA .... Oregon Department of Agriculture
ODEQ.................... Oregon Department of Environmental Quality
ODF....................... Oregon Department of Forestry
ODFW .... Oregon Department of Fish and Wildlife
ODOT .... Oregon Department of Transportation
OFWC .... Oregon Fish and Wildlife Commission
OWEB .... Oregon Watershed Enhancement Board
PBL .... Pacific Brook Lamprey
PLCI .... Pacific Lamprey Conservation Initiative
PGE....................... Portland General Electric
PIT......................... Passive Integrated Transponder
PL.......................... Pacific Lamprey
PS.......................... population stratum (singular) or population strata (plural)
PSP .... Pesticide Stewardship Partnership
RME .... Research, monitoring, and evaluation
RMU .... Regional Management Unit (USFWS)
RSC....................... Rogue/South Coast population stratum (ODFW)
S .... seconds
SDM .... Species Distribution Models
SMU .... Species Management Unit (ODFW)
Spp........................ species (plural)
SSL .... Sensitive Species List
TPLRP................... Tribal Pacific Lamprey Restoration Plan (CRITFC 2011)
US .... Upper Snake population stratum (ODFW)

USACE.................. U.S. Army Corps of Engineers
USBR.................... U.S. Bureau of Reclamation
USFWS................. U.S. Fish and Wildlife Service
Vs.......................... versus
WI.......................... Willamette population stratum (ODFW)
WBL...................... Western Brook Lamprey
WRL...................... Western River Lamprey
Yrs......................... years

Glossary

Abiotic: Environmental factors.

Adaptive genetic markers: Genetic markers subject to natural selection; i.e., to evolutionary (adaptive) change.

Adults: Life stage in which the lamprey are in various states of sexual maturation (including immature on through spawning). Unlike juveniles, sexually immature adults are no longer feeding, and are actively migrating up into freshwater (Clemens et al. 2010, 2013; Docker et al. 2015).

Ammocoetes: Greek word for "burrower in the sand". See term, "Larvae".

Anadromous: Particular life history strategy whereby juveniles rear and feed in the ocean to adult sizes, and then migrate back into freshwater to reproduce. Their offspring reside in freshwater for variable amounts of time before migrating downstream and into the ocean. Two species of anadromous lampreys are covered in this plan: Pacific Lamprey and Western River Lamprey.

Approaching flow: Volume of instream water per unit time flowing perpendicular to (into) a water diversion/screen.

Approach velocities: Speed of instream water per unit time flowing perpendicular to (into) a water diversion/screen.

Artificial propagation: Hatchery-rearing of fish.

Bioaccumulate: Physiological process of accumulating and thereby concentrating a substance by biological means. For example, this process can occur in parasitic lampreys that may store trace amounts of pollutants from the prey they feed on, which overtime can lead to a significant amount of pollutants, gathered from the bodies of multiple individual prey species. For example, see Drevnick et al. (2006).

Biota: Organisms.

Biotic: Living factors.

Branchial pores: Gill openings on lampreys, through which they breathe. Lampreys typically have seven branchial pores.

Brown: An informal, imprecise life stage classification for larval lampreys. This grouping may include various lamprey species of various life stages, but otherwise typically (but not exclusively) implies larval Pacific Lamprey. Contrast with **silver**.

Cartilage: Spongy, semi-rigid tissue.

Cryptic: Secretive, obscure, not obvious.

Depositional areas: Areas in streams in rivers with little to negligible current, where fine sediments, organic material, and small larval lamprey tend to settle out of the water column and deposit onto the substrate.

Depredate: To prey on.

Detritus: Debris from various origins and dead plant or animal material.

Diatoms: Particular taxonomic group of aquatic algae that photosynthesize like other plants.

Domestication selection: Process of evolution executed by humans on animals in controlled and artificial conditions that results in selection for a suite of biological traits that may be adaptive to the artificial environment, and conversely a suite of similar or other biological traits that may be deleterious in the natural environment.

Dorsal fins: Fins positioned on the back of fishes.

Ecology: Interactions between abiotic and biotic factors.

Ecological sink: Description of a particular object or process that inhibits ecological processes (Chen et al. 2008).

Ecosystem: Communities of biological organisms that interact with each other and with the surrounding environment.

Ecosystem engineers: Organisms that perform work on their surrounding physical habitat, moving and shaping it in a way that affects subsequent physical, chemical, and biological processes and ecological interactions among organisms.

Ecosystem services: Ecological commodities provided by a particular organism to an ecosystem that benefits ecological processes, including the abundance and diversity of other organisms.

Ecosystem function: Management of the appropriateness and sustainability of human uses dictated by the constraints imposed by the biological, physical, and legal arenas (Brussard et al. 1998).

Eyed: An informal, imprecise life stage classification for **juvenile** lamprey (see also **macrophthalmia**). This term may include various lamprey life stages and species (e.g., adult resident lampreys or juvenile anadromous lampreys), but otherwise typically (but not exclusively) implies a juvenile Pacific Lamprey.

Fecundity: The maximum number of offspring that can be produced, which is typically determined by the number of eggs a female is able to produce.

Federal Columbia River Power System: System of 31 hydropower dams owned and operated by the Bureau of Reclamation, U.S. Army Corps of Engineers, and Bonneville Power Administration on the Columbia River and its tributaries including the Snake River.

Fine particulate matter: Very small (i.e., often times microscopic) particles of **abiotic** or **biotic** origin.

Global mass extinction events: Catastrophic events that resulted in significant die-offs of all organisms from various taxa.

Hyporheic: Cool, subsurface water seeps into surface waters.

Hypothesis: Educated, testable answer posited by scientists to explain certain phenomena.

Hypothesized: Act of having formed a **hypothesis**.

Juveniles: Life stage existing only in parasitic lampreys. (Resident lampreys that do not feed during their adult stage do not have a juvenile life stage.) This is the preferred term for parasitic lampreys that have transformed from larvae into eyed, sex-determinant (male or female) small versions of the adults they will become. That is, in addition to eyes, this life stage bears sharp teeth and an **oral disc**. Juveniles rear in the ocean where they feed on various prey and grow to the species' maximum body size prior to migrating back to freshwater to spawn. Juveniles are sexually immature.

Keratinized: Hard, dead tissue of a particular type and developmental origin. The same type of material that makes up human fingernails.

Keystone species: Important species to ecosystems that by virtue of their existence and ecological interactions, determine the ecological interactions of many other organisms, and thereby the habitat structure.

Lamprey passage structures: Human-fabricated structures designed to facilitate upstream passage of adult Pacific Lamprey at artificial obstructions. These structures are typically (but not always) created through rigorous design and engineering processes.

Larvae: Larval lamprey (~0.3 in) typically dislodge from gravel interstitial spaces ~3 – 4 weeks after fertilization (Meeuwig et al. 2005; Renaud 2011; Lampman et al. 2016) and disperse downstream until suitable burrowing habitat is found or spring flows subside (Dawson et al. 2015). Eyeless, filter-feeding life stage that usually resides in the substrate (soft, silt/sandy substrate with organic material is usually preferred). This life stage of lamprey is "sex indeterminant" (i.e., the sex is not yet determined). The larval life stage lasts for 3 – 7 yrs, and occasionally may reach 8 yrs old (Dawson et al. 2015; Moser et al. 2015a) or even older (CRITFC, unpubl. data). This term is often confused with other life stages (e.g., "juvenile"; "emigrants"; "outmigrants").

Limiting factors: The physical, biological or chemical conditions of the environment that constrain the abundance, productivity, diversity or distribution of a population or species.

Macrophthalmia: Term used for “large eyes”. See **juvenile**.

Metamorphosis: Synonymous with transformation.

Microbes: Microscopic organisms.

Microphagous feeding: Feeding on tiny food particles.

Neutral genetic markers: Genetic markers *not* subject to natural selection; i.e., to evolutionary (adaptive) change.

Nocturnal: Active at nighttime.

Normal: Informal descriptor for body size of some Pacific Lamprey (≥ 21 in) in relation to “dwarf” body sizes (< 15 in), per Kostow (2002) and Hess et al. (2013). Contrast with **praecox**.

Oceanographic regime change: Complex switching between cool phase and warm phase in marine ecosystems, and affecting the chemical, physical, and biological characteristics of these ecosystems, including the biological productivity of fish stocks. Generally conditions under a cool phase favor the productivity of **anadromous salmonid** stocks, and have heretofore unknown effects on anadromous lampreys. Refer to the text near the end of Chapter 5 for further discussion of oceanographic regimes changes relative to anadromous lampreys. Oceanographic regime changes are the result of the Pacific Decadal Oscillation and El Nino-Southern Oscillation.

Ocean maturing: One of two life history strategies recently identified for adult Pacific Lamprey (see also **stream maturing**; Clemens et al. 2013). This life history can be roughly equated with the winter race of steelhead, and it is hypothesized to spawn within several weeks of entering freshwater. This ocean maturing life history has only been found in the Klamath River estuary, and it is not known if it exists elsewhere because no study has yet been designed to adequately monitor for this life history elsewhere — that is, at the interface of seawater and freshwater (Clemens et al. 2013, 2016).

Oral disc: Mouth of a lamprey.

Osmoregulatory: Physiological process of regulating ion and water balances by fishes, in their bodies.

Paired fins: Anatomical positioning of fins on either side of the body that can enable particular swimming, movement, or station-holding patterns. Possessed by bony fishes (excluding lampreys).

Paired species: Lampreys that have originally been described as two separate species, and include a parasitic stem species and a single derived species that is a resident, non-parasitic species. These two species are genetically closely related and can interbreed (Beamish and Neville 1992; Docker et al. 1999; Renaud 2011; Potter et al. 2015). In some cases Western River Lamprey may actively interbreed with either of the brook lampreys or even be produced by them, in which case Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey may not necessarily be independent species, but rather different life history types. Further, in some cases, Western River Lamprey may mediate the gene flow within and among populations of brook lamprey (Docker 2009). However, the relationship between species pairs may differ depending on the pair and the geographical location. For example, some pairs may be indistinguishable as individual species (with reproduction occurring), whereas others may be sufficiently differentiated that they function like two distinct and independent species (Docker 2009).

Periphyton: Thin film of algae that photosynthesize and grow on the surface of structures in the river environment.

Phenotypic: Physical, biological, and physiological expression of an organism — that is, the characteristics exhibited by that organism.

Pheromones: Physiologically synthesized chemical compounds by lampreys that they emit and that can serve as a means of chemical communication — and a positive attractant among them.

Photophobic: Negative response to light.

Phytoplankton: Microscopic plants that create energy from sunlight, and provide a food source for **zooplankton**.

Pinniped: Of or relating to the taxonomic classification of seals and sea lions.

Population strata: Management units or areas (plural) comprising several watersheds but smaller than a Species Management Unit. The seven population strata in the CPL are presented in Figure 2.10.

Population stratum: Management unit or area (singular) comprising several watersheds (plural) but smaller than a Species Management Unit.

Praecox: Life history of lamprey used (primarily by international biologists) to describe individuals with a body size and **fecundity** below average, and which exhibit upstream migration timing and distances different from typical individuals of the species. Contrast with **normal.**

Redds: Depressions in a gravel-dominated portion of stream or river bed excavated by sexually-mature lampreys and in which they spawn.

Resident: Life history strategy whereby a species spends its entire life in freshwater (i.e., the opposite of the anadromous life history). Two species of resident lamprey, sometimes collectively called "brook lampreys" in this plan are: Western Brook Lamprey and Pacific Brook Lamprey.

Riparian: Habitat along the edge of streams.

Salmonids: Taxonomic group of salmon and trout species in the genus *Oncorhynchus*, including (but not limited to): Steelhead, Rainbow Trout, Coho Salmon, Chinook Salmon, Chum Salmon, Sockeye Salmon, and Pink Salmon.

Satellite species: Term used for a parasitic species and multiple species that are derived (satellite) from the parasitic species. The derivative species can include both parasitic and non-parasitic lampreys (Salewski 2003; Docker et al 2009). Derivative species can be both paired and satellite. For example, Western River Lamprey is paired with Western Brook Lamprey, and it is also paired with Pacific Brook Lamprey. Western Brook Lamprey and Pacific Brook Lamprey can collectively be called satellite species to Western River Lamprey.

Sedimentation: Process in which fine animal or plant matter and small rocks, silt, clay or sand suspended in the water column is deposited onto the streambed.

Silver: An informal, imprecise life stage classification for **juvenile**, **anadromous** lampreys. This grouping may include various lamprey species of various life stages (e.g., juvenile or adult Western River Lamprey; juvenile Pacific Lamprey), but the term otherwise typically (but not exclusively) implies juvenile Pacific Lamprey. Contrast with **brown**.

Species Management Unit: Management unit or area (singular) comprising **population strata**. The Species Management Unit for lampreys in this conservation plan comprises seven population strata (Figure 2.10).

Species Distribution Models: Statistical models that use presence/absence data of particular species and environmental data to predict the probability of that species' distribution.

Strata: See **Population Strata**

Stratum: See **Population Stratum**.

Stream maturing: One of two life history strategies recently identified for adult Pacific Lamprey (see also **ocean maturing**; Clemens et al. 2013). This life history can be roughly equated with the fall race of steelhead, and likely spawn within one or more years of entering freshwater (Clemens et al. 2013).

Substrate: River or stream bottom inorganic or organic materials. Inorganic substrate includes silt, sand, pebbles, cobbles, boulders, and bedrock. Fine particles, leaves, wood, and plants are examples of organic substrate.

Sweeping flow: Stream currents "…that run parallel to the screen face and promote fish movement across, not into, the screen…" (Crandall et al. 2013)

Swim bladder: Anatomical structure found in bony fishes (excluding lampreys) that holds air and is used for maintaining buoyancy in the water column by the fish that have them.

Thalweg: Deepest portion of a stream channel that typically has the strongest water flow.

Threats: Processes or actions (human-induced or natural) that have the potential to act on or create **limiting factors** to constrain the abundance, productivity, diversity or distribution of populations or species.

Tongue piston: Part of juvenile, parasitic lamprey anatomy emanating from the central area of a lamprey's mouth. The tongue piston may be the most rigid structure in its body, and is used for rasping holes through the skin of prey species prior to feeding on their flesh. blood and, body fluids.

Transformation: Physiological process of transitioning from the larval to the juvenile (in the case of parasitic lampreys) or the larval to adult life stage (in the case of brook lampreys).

Transformer: See preferred term, "juvenile". In some situations, this term is appropriate in that it can be carefully used to describe a the stage in between larva and juvenile (in the case of parasitic lampreys) or between larva and adult (in the case of brook lampreys), if the transformation is incomplete.

Transformed: Completion of the **transformation** process.

Translocation: Management strategy used to reintroduce or augment population(s) of Pacific Lamprey upstream, in watersheds far from the Pacific Ocean. This strategy entails collecting adult Pacific Lamprey at dams low in the Columbia River Basin, and then either directly transferring them to receiving water basins or holding them overwinter in holding facilities prior to releasing them the following spring.

Turbidity: Process in which fine animal or plant matter and small rocks, silt, clay or sand originating from bank erosion into a stream and hydrologic action on the streambed results in this matter becoming suspended in the water column.

Unidirectional flow: Non-turbulent flow that is mostly in one direction.

Upwelling: Physical, chemical, and biological processes initiated by the movement of surface waters near shore, and the subsequent filling of the void left by those waters moving away by deeper water that wells up in its place. Upwelling brings nutrients to the surface that aid **phytoplankton** growth, and thereby provide food sources for **zooplankton**, the small fishes that eat these, and the larger animals that each small fishes.

Vertebrates: Class of animals possessing backbones (e.g., fishes, reptiles, birds, mammals, humans, etc.).

Zooplankton: Microscopic animals consumed by young fishes.

Appendices

Appendix 1. List of common and scientific names

Common name	Scientific name
American Mink	*Mustela vison*
American Shad	*Alosa sapidissima*
Arrowtooth Flounder	*Atheresthes stomias*
Atka Mackerel	*Pleurogrammus monopterygius*
Bald Eagle	*Haliaeetus leucocephalus*
Bigfin Eelpout	*Aprodon cortezianus*
Blue Heron	*Ardea herodias*
Blue Shark	*Prionace glauca*
Blue Whale	*Balaenoptera musculus*
Bluntnose Sixgill Shark	*Hexanchus griseus*
Brandt's Cormorant	*Phalacrocorax penicillatus*
Bullhead catfishes	*Ameiurus* spp.
California Gull	*Larus californicus*
California Sea Lion	*Zalophus californianus*
Caspian Tern	*Sterna caspia*
Channel Catfish	*Ictalurus punctatus*
Chinook Salmon	*Oncorhynchus tshawytscha*
Chiselmouth	*Acrocheilus alutaceus*
Chum Salmon	*Oncorhynchus keta*
Coho Salmon	*Oncorhynchus kisutch*
Common Carp	*Cyprinus carpio*
Cormorants	*Phalacrocorax* spp.
Crappie	*Pomoxis* spp.
Double Crested Cormorant	*Phalacrocorax auritus*
English Sole	*Parophrys vetulus*
Fin Whale	*Balaenoptera physalus*
Flathead Sole	*Hippoglossoides elassodon*
Forster's Tern	*Sterna fosteri*
Goose Lake Lamprey	*Entosphenus* spp. (unresolved taxonomy)
Great Blue Heron	*Ardea herodias*
Greenland Halibut	*Reinharditus hippoglossoides*
Humpback Whale	*Megaptera novaeangliae*
Jack Mackerel	*Trachurus* spp.
Kamchatka Flounder	*Atheresthes evermanni*
Klamath Lake Lamprey	*Entosphenus* spp. (unresolved taxonomy)
Klamath River Lamprey	*Entosphenus similis*
Lingcod	*Ophiodon elongatus*
Miller Lake Lamprey	*Entosphenus minimus*
Northern Anchovy	*Engraulis mordax mordax*
Northern California Brook Lamprey	*Entosphenus folletti*
Northern Elephant Seal	*Mirounga angustirostris*

Northern Fur Seal	*Callorhinus ursinus*
Northern Pikeminnow	*Ptychocheilus oregonensis*
Osprey	*Pandion haliaetus*
Pacific Brook Lamprey	*Lampetra pacifica*
Pacific Cod	*Gadus macrocephalus*
Pacific Hake	*Merluccius productus*
Pacific Halibut	*Hippoglossus stenolepis*
Pacific Harbor Seal	*Phoca vitulina richardii*
Pacific Herring	*Clupea pallasii pallasii*
Pacific Lamprey	*Entosphenus tridentatus*
Pacific Ocean Perch	*Sebastes alutus*
Pacific Salmon	*Oncorhynchus* spp.
Petrale Sole	*Eopsetta jordani*
Pile surfperch	*Rhacochilus vacca*
Pink Salmon	*Oncorhynchus gorbuscha*
Pit-Klamath Brook Lamprey	*Entosphenus lethophagus*
Raven	*Corvus corax*
Ringbill Gull	*Larus delawarensis*
River Otter	*Lutra canadensis*
Rougheye Rockfish	*Sebastes aleutianus*
Roughscale Sole	*Clidoderma asperrimum*
Sablefish	*Anoplopoma fimbria*
Salmonids	*Oncorhynchus* spp.
Sculpin species	*Cottus* spp.
Sea Lamprey	*Petromyzon marinus*
Sei Whale	*Balaenoptera borealis*
Shiner Perch	*Cymatogaster aggregata*
Shortraker Rockfish	*Sebastes borealis*
Smallmouth Bass	*Micropterus salmoides*
Sockeye Salmon	*Oncorhynchus nerka*
Speckled Dace	*Rhinichthys osculus*
Sperm Whale	*Physeter macrocephalus*
Spiny Dogfish Shark	*Squalus acanthias*
Starry Flounder	*Platichthys stellatus*
Steelhead/Rainbow Trout	*Oncorhynchus mykiss*
Steller Sea Lion	*Eumetopias jubatus*
Salmon and trout	*Oncorhynchus* spp.
Striped Bass	*Morone saxatilis*
Terns	*Sterna* spp.
Walleye	*Stizostedion vitreum*
Walleye Pollock	*Gadus chalcogrammus*
Western Brook Lamprey	*Lampetra richardsoni*
Western Gull	*Larus occidentalis*
Western Pond Turtle	*Clemmys marmorata*

Western River Lamprey	*Lampetra ayresii*
White Sturgeon	*Acipenser transmontanus*
Widow Rockfish	*Sebastes entomelas*
Yellow Bullhead	*Ameiurus natalis*
Yellowmouth Rockfish	*Sebastes reedi*

Appendix 2. Recommended life stage terminology

At least 11 different terms are used interchangeably to describe life stages of lampreys (Clemens 2019). Additional descriptive terms are commonly used in various datasets, including: "brown", juvenile, and "silver". Some of these terms are defined in the Glossary and are compared in Table A2.1. These terms may appear as jargon to non-experts (e.g., "ammocoetes"; "macrophthalmia"), and are often used imprecisely and inaccurately across different life stages and species. Jargon and inconsistent terminology can confuse attempts to compare datasets and publications. Based upon simplicity and logical precedents set forth by Balon (1975) and Docker et al. (2015), the following five stages of post-hatch terminology are recommended: 1) Larva (immature, non-sex determinant, filter-feeding lamprey without eyes); 2) transformer (stage between larva and juvenile in the case of parasitic lampreys, and between larva and adult in resident brook lampreys); 3) juvenile (metamorphosed individual with eyes, for species with a parasitic lifestyle); 4) adult (non-feeding, upstream-migrating lamprey in various stages of sexual maturation); and 5) senescent (post-spawned lamprey in the process of dying; Table A2.1; Clemens 2019).

Table A2.1. Comparison of life stages terminology for lampreys.

Preferred life stage name	Definition	Species	Synonyms	Confused with	Imperfect synonyms
Larva	Immature, filter feeding life stage that reside primarily in burrows in soft sediment	Parasitic and resident (brook) lampreys	Ammocoetes	Juvenile; Emigrant; Out-migrant	"brown"
Transformer	Stage intermediate to larva and juvenile for parasitic lampreys and intermediate to larva and adult for resident, brook lampreys	Parasitic and resident (brook) lampreys	Smolt; metamorphic phase	Juvenile; Emigrant; Out-migrant; Adult	"eyed"; "silver"
Juvenile	Transformed individuals	Parasitic lampreys	Macrophthalmia; Transformers	Larva; Adult	"eyed"; "silver"
Adult	Non-feeding, upstream-migrating lamprey in various stages of sexual maturation	Parasitic and resident (brook) lampreys	–	Juvenile	–
Senescent	Spawned out, dying lamprey	Parasitic and resident (brook) lampreys	–	Adult; Kelt [a]	–

[a] Lampreys spawn during one season and then die (Johnson et al. 2015). Little evidence has been reported to suggest otherwise and this evidence should be scrutinized carefully (Clemens 2019).

Appendix 3. Diversity and ecology of lampreys

DIVERSITY

This section begins with a discussion of life history diversity. Next, paired species are discussed, including the emerging hypothesis that some lamprey species may be different life histories of the same species. Finally, genetic population structure within species is discussed.

Life history diversity

Life history diversity has been observed and described exclusively in adult Pacific Lamprey. This may be because Pacific Lamprey are more ubiquitous, conspicuous, and desirable for harvest; as such, this lamprey species may be more frequently observed and scrutinized. Information on life history diversity is lacking for other lampreys. This section therefore focuses on life history diversity in adult Pacific Lamprey. Four different terms have been used to describe the life history diversity of adult Pacific Lamprey, including: 1) "stream maturing" and "ocean maturing", 2) "day eels" and "night eels", 3) "normal" and "praecox", and 4) "normal" and "dwarf". Each of these pairs of terms is described below. No empirical evidence is available to indicate whether some or all of these terms describe the same life history or multiple life histories.

Ocean maturing and stream maturing life histories of Pacific Lamprey have recently been identified, which approximate the winter and summer runs of steelhead (Clemens et al. 2013). These life histories have associated genetic markers (Parker et al. 2019). The ocean maturing life history is hypothesized to spawn within several weeks of entering freshwater. The stream maturing life history is hypothesized to spawn within one or more years of entering freshwater. The ocean maturing life history has only been identified from the Klamath River (Clemens et al. 2013; Parker et al. 2019). To date no study has been designed to monitor for ocean maturing Pacific Lamprey in Oregon (Clemens et al. 2013, 2016).

Tribes of the Coastal and interior Columbia River have identified and described day and night eels (lamprey). Day eels are small in body size and light in color. Night eels are large in body size, dark in color, and have a more desirable taste when eaten (Downey et al. 1993; Close et al. 2004; Sheoships 2014). Day eels may be lamprey that held in freshwater for long time, whereas night eels may be lamprey that are recent migrants. Alternatively day eels and night eels could be two different life histories (Close et al. 2004).

The terminology for normal and praecox forms of lampreys originated among international biologists. "Normal" denotes a typical body size, fecundity, and migration timing for a particular life history, whereas "praecox" denotes individuals with body sizes and fecundities that are smaller and lower than average, respectively, and different upstream migration timing and distances (Docker 2009; Renaud 2011). The term "dwarf" rather than praecox is often used to describe small-bodied forms of Pacific Lamprey in Oregon (Kostow 2002; Hess et al. 2013) and the terms praecox and dwarf appear to be synonymous — although this may not necessarily be the case. Normal and dwarf life histories of Pacific Lamprey have been observed in the Coquille River (Kostow 2002). The dwarf life history has been observed to spawn at a different time within the same season (Kostow 2002). A wide range of body sizes of Pacific Lamprey have been observed in rivers of British Columbia (range: 5 – 28 in; Beamish 1980). The small end of this range, 5 in, seems incredibly small in comparison to more common body lengths of 13 – 33 in (Table 2.1). The dwarf life history of Pacific Lamprey has been defined as being < 15 in long versus a "normal size" of ≥ 21 in (Kostow 2002; Hess et al. 2013).

Paired species / satellite species

Paired species are lampreys that were originally described as separate species, and include a parasitic species and a single derived species that is a resident, non-parasitic species. Paired species are genetically related and can interbreed (Beamish and Neville 1992; Docker et al. 1999; Docker 2009; Renaud 2011; Potter et al. 2015). In some cases Western River Lamprey may actively interbreed with Western Brook Lamprey and Pacific Brook Lamprey or even be produced by them. This suggests that Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey may not be independent species, but rather different life histories of a species. In some cases, Western River Lamprey may mediate gene flow within and among populations of brook lampreys (Docker 2009). The relationship between paired species may differ depending on the species pair and the geographical location. For example, some pairs may be indistinguishable as individual species, whereas others may be sufficiently differentiated that they behave like independent species (Docker 2009).

Satellite species is a term used to describe a parasitic species and multiple species that are derived (satellite) from the parasitic species. The derived species can include both parasitic and non-parasitic lampreys (Salewski 2003; Docker et al 2009). Derived species can be both paired and satellite. For example, Western River Lamprey is paired with Western Brook Lamprey, and it is also paired with Pacific Brook Lamprey. Western Brook Lamprey and Pacific Brook Lamprey are satellite species to Western River Lamprey. Satellite species relative to the species covered in this conservation plan are presented in Table A3.1. This information is useful to consider in a broad sense for the purposes of species diversity, distribution, and connectivity. Additional information on genetic population structure with respect to Western River Lamprey and its satellite species, Western Brook Lamprey and Pacific Brook Lamprey, can be found in the next section.

Table A3.1. Association of the Pacific Lamprey and Western River Lamprey with the resident lampreys that have evolved from them ("satellite species"). References: Vladykov and Kott (1979); Docker et al. (1999); Docker (2009); Potter et al. (2015).

Parasitic species	Satellite species	Covered in this plan?
Pacific Lamprey	Northern California Brook Lamprey	N
	Pit-Klamath Brook Lamprey	N
	Klamath River Lamprey	N
	Miller Lake Lamprey	N [a]
	Northern California Brook Lamprey	N
	Klamath Lake Lamprey	N
	Goose Lake Lamprey	N
Western River Lamprey	Western Brook Lamprey	Y
	Pacific Brook Lamprey	Y

[a] Covered in ODFW 2005.

Genetic population structure

Pacific Lamprey have been studied more thoroughly than Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey. This renders direct comparisons of genetic population structure of Pacific Lamprey relative to these other lampreys challenging. With this in mind, a simplified comparison of distribution, homing, migration, and aspects of genetic population structure is presented in Table A3.2.

Table A3.2. Descriptive comparison of the distribution, homing potential, migration and genetic population structures for lampreys. References: Goodman et al. (2008); Reid et al. (2011); Boguski et al. (2012); Spice et al. (2012); Hess et al. (2013, 2014, 2015); Clemens et al. (2017b); Spice et al. (2019)

	Pacific Lamprey	Western River Lamprey	Western Brook Lamprey	Pacific Brook Lamprey
Distribution	Broad	Low – intermediate	Intermediate	Low
Home to natal streams?	No	Unknown	Unknown	Unknown
Extensive migrations?	Yes	No	No	No
Population genetic structure				
Across broad geographic areas	Little	Yes	Yes	?
Within a basin, over time	Yes	Unknown	Unknown	Unknown
Genetic richness among populations [a]	No	Yes	Yes	No
No. of research studies	6	1	3	2
Genetic markers used (to date)	Neutral; Adaptive	Neutral	Neutral	Neutral

[a] As determined by neutral genetic markers.

Perspectives on genetic population structure of Pacific Lamprey vary depending on collection methods and genetic tools. Research using neutral genetic markers (i.e., genetic markers not subjected to evolution through natural selection) on Pacific Lamprey indicates that they exhibit a low level of genetic stock structure, with high but limited rates of gene flow across British Columbia, Washington, Oregon, and California. This research suggests that adult Pacific Lamprey do not home to streams in which they were born (Goodman et al. 2008; Spice et al. 2012). By contrast, research using adaptive genetic markers (genetic markers subjected to evolution) on Pacific Lamprey indicates high levels of genetic structuring with regards to body size and geography across British Columbia, Washington, Oregon, and northern California (Hess et al. 2013). Pacific Lamprey differ in the occurrence of adaptive genetic markers between the Coastal and Rogue/South Coast population strata and the Willamette stratum; and between each of these and the interior Columbia River Basin (Hess et al. 2013, 2014, 2015). To summarize, neutral genetic markers indicate gene flow and a lack of genetic population structure whereas adaptive genetic markers for body size, migration timing, and migration distance have been identified for Pacific Lamprey in relation to geographic regions.

Juvenile and adult Western River Lamprey are found in the ocean within the proximity of large river mouths and they may return to these rivers to spawn (Beamish 1980; Beamish and Youson 1987; Kostow 2002). If Western River Lamprey exhibit fidelity to these rivers, they may exhibit genetic population structure (Kostow 2002). The available information suggests this may be the case. The level of genetic differentiation (using neutral genetic markers) between Western River Lamprey from British Columbia versus those from Oregon was greater than between Western River Lamprey and Western Brook Lamprey from a particular geographic area (i.e., British Columbia; Boguski et al. 2012). Genetic divergence among Western River Lamprey occurred at the geographical demarcation of Cape Blanco, which delineates the Coastal and Rogue/South Coast strata.

Western Brook Lamprey exhibit significant genetic differentiation along the Oregon Coast (Boguski et al. 2012). Genetic divergence among Western Brook Lamprey occurred at the geographical demarcation of Cape Blanco, which delineates the Coastal and Rogue/South Coast strata. Genetic differentiation within the Fourmile Creek and Siuslaw River basins suggests that unique species of brook lamprey may occur there (Boguski et al. 2012). Within the Columbia River Basin and coastal Washington,"…gene flow [of Western Brook Lamprey] occurred primarily in a downstream direction, resulting in low genetic diversity in upstream sites. [Western Brook Lamprey] populations in these areas may be particularly vulnerable to local extinction" (Spice et al. 2019). The genetic diversity of Pacific Brook Lamprey has not been explored widely beyond baseline work in the Clackamas Basin (Reid et al. 2011).

ECOLOGY

The ecology of lampreys includes their interactions with the environment (abiotic) and other organisms (biotic). Abiotic aspects include the temperatures, substrates, and flows associated with habitat use by lampreys in freshwater. A review of the literature suggests the following three key points about lampreys relative to abiotic factors:

- across life stages and species of lampreys, cool water temperatures (< 68°F) are conducive to lamprey health and survival
- a wide range of substrate sizes are required for all life stages and species of lampreys for rearing, migrating, and spawning. Pacific Lamprey can ascend some wetted, inclined surfaces by a “burst-and-attach” mode of climbing
- lampreys are not strong swimmers in comparison with salmon and trout. Larvae and juveniles of the anadromous Pacific Lamprey and Western River Lamprey may use high river flows to disperse downstream and into seawater. Migrations and movements within seawater may be promoted through attachment to host prey species. Unidirectional flow and sufficient attachment surfaces in freshwater are required by adult Pacific Lamprey migrating upstream to effectively navigate through fish ladders. Pacific Lamprey use rapid “burst-and-attach” swimming to transit through areas of high water velocity en route to upstream spawning grounds. Relatively large Pacific Lamprey are more able to navigate fish ladders and to migrate further upstream than smaller-bodied Pacific Lamprey; a similar relationship is expected to occur for Western River Lamprey.

Biotic aspects of lampreys include ecosystem function, human use of lampreys, predators, prey, and population cycles. A review of the literature suggests the following three key points about lampreys relative to biotic factors:

- lampreys may be keystone species in watersheds: they perform a number of important roles in supplying nutrients to the base and tops of the food web and spawning lampreys and burrowed larvae create habitats suitable for other animals. The burrowing behavior of larval lamprey can aerate the stream bottom
- a significant number of different animal species have been documented to depredate lampreys
- a significant number of prey species have been identified for Pacific Lamprey and Western River Lamprey in the estuary and ocean. The distribution and cycles of abundance of these lampreys appear to be connected to the abundance, population cycles, and migrations of their prey items.

Environment

Temperature

Three messages can be gleaned about the thermal biology of lampreys in fresh water: 1) at < 50°F, lampreys undergo little activity, 2) temperatures ≥ 68°F can be deleterious to health and survival of lampreys in some areas of their distribution, and 3) in other areas of their distribution where higher water temperatures may be encountered with greater frequency, thermal thresholds appear to be higher. Lampreys may exhibit different temperature adaptations and thresholds across their distribution ranges (like for example in the Rogue River, which is warmer than other coastal rivers in Oregon, and the interior Columbia River Basin). The following information provides some more specificity with regards to temperatures of spawning and development of each species of lamprey. Most of the following information has occurred in the lower Columbia River Basin and coastal areas of the Pacific Northwest. Therefore, these temperatures may be slightly lower than what occurs in warmer areas of lamprey distribution.

Spawning in Pacific Lamprey occurs at average water temperatures of 50 – 63°F, and peaks at 55 – 61°F (Brumo 2006; Stone 2006). Embryonic and larval development of Pacific Lamprey can occur as cool as 41°F and up to 72°F. However, laboratory research indicates that survival of larval Pacific Lamprey was highest at 64°F, followed by 57°F. At 72°F, survival was lowest and developmental abnormalities were highest (Meeuwig et al. 2005).

Five lines of evidence from field and laboratory research and field observations in the Willamette River Basin suggest that warm water temperatures (≥ 68°F) during July – August may curtail survival, migration and successful reproduction of Pacific Lamprey far up into this watershed (Clemens et al. 2016). First, temperatures > 68°F have been associated with a large die-off of adult Pacific Lamprey at Willamette Falls. Second, water temperatures ≥ 68°F have also been associated with skewed sex ratios (more males) in one year at Willamette Falls. Third, these temperatures have been associated with damaged reproductive organs in males, which may affect their ability to mature and spawn (Clemens et al. 2016). Fourth, exposure of adult Pacific lamprey to these warm temperatures can result in a faster sexual maturation schedule (Clemens et al. 2009). Fifth, these water temperatures (≥ 68°F) have been associated with slowing and stopping of upstream migration of radio-tagged, adult Pacific Lamprey in the Willamette River Basin (Clemens et al. 2012a, b, 2016, 2017b), which may result in lamprey not spawning far up into the Willamette Basin (Clemens et al. 2016). Conversely, higher annual river flows are associated with farther migration distances upstream (Clemens et al. 2016, 2017b). In summary, this evidence suggests that warm summertime temperatures (≥ 68°F) may prevent successful reproduction by Pacific Lamprey in the upper portions of the Willamette Basin. Elsewhere, in the interior Columbia River Basin, these warm temperatures have not been associated with die-offs or physiological problems of Pacific Lamprey (Ralph Lampman, Yakama Nation Fisheries, pers. comm.; Aaron Jackson, Confederated Tribes of the Umatilla Indian Reservation, pers. comm.).

Western River Lamprey spawn at 54°F in the laboratory (Beamish 1980); this overlaps with peak spawning of both brook lampreys (see below). Given the close taxonomic status of Western River Lamprey with brook lampreys, the range of biological activity is probably similar among these species.

Given the close taxonomic status and life history of Western Brook Lamprey and Pacific Brook Lamprey and the lack of data on Pacific Brook Lamprey, it is inferred that the range of biological activity is similar between the two species. Observations of fish held in captivity suggest that male Pacific Lamprey may be more active at lower temperatures than males of Western Brook Lamprey (Pletcher 1963). Western Brook Lamprey spawn at water temperatures of 46 – 68°F (Scott and Crossman 1973; Stone 2006), and peak spawning occurs at 48 – 54°F (Scott and Crossman 1973; Renaud 2011). Embryonic and larval development of Western Brook Lamprey occur as cool as 41°F, and on up to 72°F. However, laboratory research suggests that survival of larvae of Western Brook Lamprey is highest at 64°F, followed by 57°F. At 72°F, survival was lowest and developmental abnormalities highest (Meeuwig et al. 2005).

Flows

This section focuses on some generalities and specifics of river flows and the biology of lampreys in freshwater. This section will not focus on currents encountered in estuarine and saltwater by the anadromous Pacific Lamprey and Western River Lamprey because this information is not known and because the movements of parasitic lampreys in seawater may depend on where their host prey carries them (Spice et al. 2012; Murauskas et al. 2013).

River currents play a large role in the biology of lampreys (Maitland et al. 2015). For example, flows distribute mating and migratory pheromones that attract adults to rivers, and then females to males (Maitland et al. 2015; Moser et al. 2015b). Larval and juvenile lampreys use river flows to carry them downstream and out to sea (Beamish and Youson 1987; Beamish and Levings 1991; Goodman et al. 2015; Moser et al. 2015a). Lampreys are considered weak swimmers (Moser et al. 2015a, b; PLTWG 2017) and their swimming capabilities are associated with life stage and body size. Relatively small larval and juvenile lampreys are the weakest swimmers of all life stages and much of their movements are probably as passive drifters.

Swimming capabilities relative to current velocities are best studied in Pacific Lamprey. The average, maximum speed that larval and juvenile Pacific Lamprey can swim for a brief period of time is < 3 fps, with small larvae swimming slower and relatively large larvae and juveniles swimming faster. Similarly the current velocities at which larval and juvenile Pacific Lamprey can swim for prolonged periods is low relative to other fishes (Sutphin and Hueth 2010; Dauble 2006; Moser et al. 2015a). Juvenile Pacific Lamprey often intersperse bouts of swimming with attaching to surfaces with their mouths (Moser et al. 2015a). Large adult Pacific Lamprey are stronger swimmers than small adult Pacific Lamprey. Large body sizes in adult Pacific Lamprey are associated with better passage efficiency at fishways (Keefer et al. 2009a), and longer migration distances (Keefer et al. 2009b; Clemens et al. 2010; Hess et al. 2014).

Free-flowing, dynamic rivers may be associated with more adult Pacific Lamprey (Clemens et al. 2017a). River flows attract upstream migrating adult lampreys (Clemens et al. 2016), and larger flow volumes have been associated with further migration distances upstream by adult Pacific Lamprey (Clemens et al. 2017b). Unidirectional flow tends to attract adult Pacific Lamprey to fishways. Yet high water velocities in salmon ladders are not conducive to passage by adult Pacific Lamprey because of the energy required to pass through these flows (PLTWG 2017). Conversely, lack of flow or turbulent flows appear to have the opposite effect, potentially confusing adult Pacific Lamprey attempting to migrate upstream (Moser et al. 2015b; PLTWG 2017). Adult lampreys move upstream through an alternating mode of burst swimming followed by attachment to surfaces with their suction disc mouth. Therefore, a lack of attachment surfaces in fishways can make these structures challenging if not impossible for adult Pacific Lamprey to pass (Keefer et al. 2010; PLTWG 2017). The maximum swimming speed at which adult Pacific Lamprey can swim for a limited amount of time averages about 3 fps. The maximum swimming speed at which adult Pacific Lamprey can swim for a very brief period of time averages about 7 fps (PLTWG 2017). To summarize, unidirectional flows with adequate attachment surfaces are associated with attraction, retention, and eventual passage of adult Pacific Lamprey at fishways.

Unidirectional flow is often associated with spawning by lampreys (Stone 2006; Gunckel et al. 2009; Clemens et al. 2010; Maitland et al. 2015), although it is interesting that Pacific Lamprey have also been observed to spawn in lake habitats subjected to wave action, but otherwise without apparent unidirectional current (Russell et al. 1987).

The migration characteristics and passage and swimming capabilities of Western River Lamprey have not been studied. However, it is surmised that unidirectional flows with adequate attachment surfaces may be associated with attraction, retention, and passage of Western River Lamprey in fishways, albeit at smaller scales and lower flow velocities than those negotiated by the larger Pacific Lamprey.

The migration characteristics and passage and swimming capabilities of Western Brook Lamprey and Pacific Brook Lamprey has not been studied. However, it is surmised that their passage capabilities may be much less developed than for anadromous lampreys for two reasons. One, brook lamprey have relatively small body sizes (Table 2.1) and two, they lack a large and adapted oral sucker disc, which may render their ability swim through high flow velocities and attach to surfaces more challenging than for the larger adult Pacific Lamprey. Yet this may be a moot point since brook lampreys tend to occur in shallower and hence slower moving water (Stone 2006; Gunckel et al. 2009; Johnson et al. 2015).

Substrate sizes

This section focuses on the substrate sizes and types associated with the ecology of lampreys in freshwater. The density of larval and juvenile lamprey in the substrate varies from 0.0 to 11.0 per ft^2 (Table A3.3).

Substrate size, flow velocity, and the underlying geology of watersheds are correlated and generally result in a continuum of fairly large substrate sizes higher up in watersheds relative to substrate sizes lower in watersheds. A variety of substrate types and sizes are used by all species and life stages of lampreys. Substrate use by lampreys is associated with body sizes, both across life stages and species. Across life stages within a species, larvae are generally found in areas with relatively slow water — such as depositional areas with silty and/or sandy substrate with fine organic material (Dawson et al. 2015; Reid and Goodman 2015). Deeper deposition generally equates to more area for forming burrows, and the ability to burrow into a substrate is associated with predator avoidance (Dawson et al. 2015). Depositional areas typically occur in pools, stream banks and off-channel areas (Slade et al. 2003; Torgersen and Close 2004; Schultz et al. 2014; Crandall et al. 2015). Such areas are conducive to burrowing and feeding by the larvae and are sometimes classified as “Type I” habitat by lamprey biologists (Slade et al. 2003; Crandall et al. 2015). Larval lamprey are found at significantly lower densities in “Type II” habitat, which is composed of “*shifting sand that may contain some gravel*” with little organic material (Slade et al. 2003; Crandall et al. 2015). “Type III” habitat is not conducive to burrowing by larval lamprey, and therefore few, if any larvae would be expected to be present. Type III habitat consists of any combination of hardpan clay, hard packed gravel or bedrock with negligible organic material (Slade et al. 2003; Crandall et al. 2015). This three-tiered system for classifying habitats for larval lampreys is useful for generalizations, however larval lamprey distribute among various habitats (Schultz et al. 2014), and this may be partly due to habitat availability and/or self-distributing to avoid high densities of other larval lampreys.

Table A3.3. Range of densities and mean density (larvae per ft^2) from studies that actively sampled substrate. PL = Pacific Lamprey; WRL = Western River Lamprey; WBL = Western Brook Lamprey.

Density range [a]	Average density range	Species	Habitat	Depth (ft)	Study
–	~1.0 [b]	PL; WBL	Fish salvage over 7,100 ft^2	Dewatered	C. Claire, ODFW, pers. comm.
0 – 0.1	–	WBL	Wadable streams	0.3 – 1.6	Schultz et al. (2014)
0 – 0.4	–	PL	Wadable streams	0.3 – 1.6	Schultz et al. (2014)
–	> 0.4 [a]	PL	Fish salvage over 75,000 ft^2	Dewatered	P. Burns, USFS, pers. comm.
0 – 3.1	0 – 0.2	PL	Tributary mouths	2.0 – 27.9	Harris and Jolley (2016)
0 – 3.5	0 – 0.2	WBL / WRL	Tributary mouths	1.0 – 27.9	Harris and Jolley (2016)
0.3 – 6.0	2.4 – 2.6	WRL	Estuary	0 – 18.4	Beamish and Youson (1987)
0.0 – 11.0	0.0 – 1.9	PL	Wadable streams	0.3 – 1.3	Torgerson and Close (2004)

[a] Minimum to maximum.

[b] One-time enumeration, range of minimum to maximum numbers does not apply.

Juvenile lampreys migrating downstream (i.e., the anadromous and parasitic Pacific Lamprey and Western River Lamprey), can be found in gravel substrate, such as in riffles and elsewhere. Juveniles are more likely than larval lamprey to be found on or near the surface of the stream bottom.

Returning adult Pacific Lamprey have been associated with a variety of substrates, including boulders (Robinson and Bayer 2005; Clemens et al. 2012a; Starcevich et al. 2014), bedrock, within rock revetments, and large woody debris (Clemens et al. 2012a). Interestingly, some people have occasionally found an adult Pacific Lamprey buried under the gravel of a streambed, and this type of behavior has been reported for adults of other species of parasitic and non-parasitic lampreys as well (Renaud 2011). Taken together, the use of these substrates by lampreys could suggest a behavioral tactic for avoiding predators. Adult Pacific Lamprey can vertically ascend some geologic features like certain water falls. They do this by affixing their oral discs to the wetted rock, contracting their bodies to propel them a few inches upward while freeing mouth adhesion from the rock, and then reattaching a few inches higher (i.e., "burst-and-attach"; Clemens et al. 2010; Moser et al. 2015b). Aluminum ramps (60 – 90° inclines), with a thin film of water running through them, have been constructed and installed at various dams to take advantage of this climbing behavior to promote passage of adult Pacific Lamprey (Moser and Mesa 2009; Moser et al. 2011; Jackson and Moser 2012).

Pacific Lamprey spawn in habitats similar to salmonids: in pool tail-outs, upstream of riffle crests, and runs or low gradient riffles, in predominately gravel-bottomed streams (Stone 2006; Gunckel et al. 2009; Mayfield et al. 2014). The dimensions of Pacific Lamprey redds are quite variable across studies conducted in different watersheds in Washington and Oregon. The longevity of Pacific Lamprey redds has been estimated to average 40 days (range: 10 – 97 days; Stone 2006).

The substrate size used by Western River Lamprey has not been studied. However, given this species' inter-relatedness with the brook lampreys it may use similar substrate in a similar way.

Adult Western Brook Lamprey remain burrowed into the gravel substrate of the streambed until they emerge to spawn (Pletcher 1963). Transformed adult brook lampreys are associated with gravel sizes used for spawning, which tend to be smaller and in shallower water than those used by Pacific Lamprey (Stone 2006; Gunckel et al. 2009; Johnson et al. 2015). This may have something to do with the ability of the relatively small Western Brook Lamprey to hold station in the stream current, create redds, and spawn without being swept downstream. With this in mind, it is interesting that Western Brook Lamprey are occasionally observed constructing nests or spawning within the redds of Pacific Lamprey (Stone 2006; Gunckel et al. 2009). Western Brook Lamprey tend to spawn in pool tail-outs, upstream of riffle crests, and in runs in gravel bottom streams, on finer substrates and in shallower water than Pacific Lamprey (Stone 2006; Gunckel et al. 2009). Western Brook Lamprey redds are often associated with rock, wood, and plant cover (Gunckel et al. 2009). The longevity of Western Brook Lamprey redds has been estimated to average 37 days (range: 21 – 69 days; Stone 2006). Owing to their related ancestry (Chapter 2) and body sizes (Table 2.1), it is presumed that Pacific Brook Lamprey spawn in habitats similar to those of Western Brook Lamprey.

Depths

This section focuses on three topics for which information is available: 1) fluctuations in water depth encountered by larvae burrowed in the substrate, 2) water column depths of larvae and juveniles of Pacific Lamprey during their outmigrations to the sea, and 3) the depths at which Pacific Lamprey and Western River Lamprey are found in seawater. Given their distributions and freshwater residency, it is surmised that adults of Western Brook Lamprey and Pacific Brook Lamprey typically occur in relatively shallow freshwater.

Developing eggs, larvae, and adult lampreys may be subjected to fluctuations in water levels from flood events or from human causes, including instream work, water diversions, and dams. Human-caused fluctuations can lead to rapid dewatering, resulting in desiccated eggs; stranded, dead, or larvae consumed by predators; and dry habitat that would otherwise be encountered by adults during their upstream migrations (Close et al. 2009; Streif 2009; Maitland et al. 2015; Clemens et al. 2017a). Provided they remain wet and temperature is not excessively warm, larval lamprey can breathe through their skin, potentially enabling them to live for up to several days (Potter et al. 1996; Clemens et al. 2017a). It is not entirely clear, but adults may have some limited capabilities to breathe through their skin if they are kept moist and cool (Coolidge et al. 2007) — and such conditions may occur at water falls (e.g., Willamette Falls).

Larval lamprey (Pacific Lamprey and/or Western River Lamprey and Western Brook Lamprey) have been detected in the substrates of the lower Willamette River, in depths down to 52 ft (Jolley et al. 2012), and in substrates of river mouths of tributaries entering the Columbia River at depths of 1 – 28 ft (Harris and Jolley 2016). Larvae are commonly found at shallower depths associated with shallow habitats conducive to monitoring (Table A3.3).

Outmigrating juvenile Pacific Lamprey tend to be found in the thalweg of rivers and occur deeper in the water column than more surface-oriented, outmigrating juvenile salmonids. The lack of a swim bladder renders lamprey heavier than the surrounding water and they are suited to swimming near the river bottom (Moser et al. 2015a). Unlike juvenile salmon, juvenile Pacific Lamprey and Western Brook Lamprey subjected to hydrostatic pressure changes that mimicked what would occur at turbine passage did not yield barotrauma-related injuries, nor did they exhibit immediate or delayed mortality (Colotello et al. 2012 — cited in Moser et al. 2015a).

In the open ocean, Pacific Lamprey are found between the surface and 4,872 ft (Orlov et al. 2008a). However, Pacific Lamprey are most often found between the surface and 1,640 ft (Orlov et al. 2008a; Wade and Beamish 2016). In the Strait of Georgia and near Vancouver Island, Pacific Lamprey were commonly captured at 102 – 328 ft, followed by 331 – 1,640 ft (Wade and Beamish 2016). At depths of 328 – 820 ft, Pacific Lamprey have been found in association with their prey, including Walleye Pollock and Pacific Hake (Beamish 1980). Similarly, the biggest catches made through NOAA Fisheries surveys occurred at open water survey depths of 328 – 984 ft (bottom depths were 328 – 2,625 ft), and the largest catches of Pacific Lamprey were from surveys designed to detect Pacific Hake (L. Weitkamp et al., NOAA Fisheries, unpubl. memo). However, during a recent year, a very large catch of adult Pacific Lamprey was made in association with a school of Walleye Pollock at a depth of 148 ft (Wade and Beamish 2016). Pacific Lamprey make daily vertical migrations up into in the water column at night and deeper during the day, which have been linked with movements of their prey, Walleye Pollock (Orlov et al. 2008a). Taken together, this information strongly suggests that the depth of occurrence of Pacific Lamprey is associated with where Walleye Pollock and Pacific Hake occur. Indeed Walleye Pollock appears to be the preferred prey item for Pacific Lamprey in the Strait of Georgia, whereas Pacific Hake may be the preferred prey item elsewhere on the Pacific Coast of North America (Orlov et al. 2008a; Wade and Beamish 2016).

Western River Lamprey are found in surface waters of estuaries and the nearshore ocean, typically within 98 ft of the surface, and they are less abundant at depths down to 328 ft. At shallow depths, Western River Lamprey are captured in association with schools of Pacific Herring (Beamish 1980; Wade and Beamish 2016).

Interactions with other organisms

Ecosystem function

Lampreys likely provide substantial benefits to their ecosystems, and these can be placed into three categories: 1) "ecosystem engineers"; 2) nutrient suppliers to freshwater ecosystems and recyclers of nutrients within these systems; and 3) prey sources for other animals / predation buffers to salmonid species.

As "ecosystem engineers" lampreys benefit the surrounding habitat in freshwater streams in ways that differ by life stage. For example, as adults, lampreys construct redds in which they spawn. Construction of these redds alters the streambed in ways that favor aggregations of aquatic insects that process stream nutrients and feed juvenile fishes (Hogg et al. 2014). In addition, the burrowing behavior of larval lamprey has been associated with increased water exchange between the stream and substrate in the streambed, increased oxygen in the substrate, and an increase in fine particulate matter on the surface of the substrate (Shirakawa et al. 2013; Boeker and Geist 2016).

Anadromous lampreys provide marine-derived nutrients to freshwater ecosystems (Close et al. 2002; Nislow and Kynard 2009). Their spawned-out carcasses decay and release nutrients into the surrounding water (Weaver et al. 2015). These nutrients are assimilated by aquatic insects (Weaver et al. 2016), which may be consumed by juvenile salmonids. As nutrient recyclers, larval lamprey feed on detritus and algae and convert these food sources into energy stored as animal (larval lamprey) tissue (Close et al. 2002) that is then available to larger predators that eat them. Lampreys are a prey source for humans (see below) and many different animals (Table A3.4).

Two different lines of evidence suggest that larval lampreys may feed on algal and microbial growth of spawned-out salmon carcasses. First, Russian biologists have recorded the presence of larval lamprey (different species than in Oregon) in salmon carcasses (Kucheryavyi et al. 2007), and concluded that the lamprey larvae were grazing on algae and microbes that grow on salmon carcasses. Similar observations have been made by experienced salmon surveyors working for or with ODFW in coastal streams in Oregon.

Larval and juvenile lampreys migrating downstream may focus the attention of predatory fishes and birds, thereby potentially offering a predation reprieve for juvenile salmon and steelhead. Similarly, the high caloric content, ease of capture (relative to salmonids), and the tendency to migrate in schools may make Pacific Lamprey desirable prey sources for pinnipeds, thereby buffering adult salmon and steelhead from predation (Close et al. 2002).

Human use

Native Americans were the first humans to harvest adult Pacific Lamprey in Oregon (Mattson 1949; Downey et al. 1996; Close et al. 2002). Harvest typically occurred where geologic formations formed obstructions (e.g., waterfalls) where Pacific Lamprey would congregate (Close et al. 2002). Historically, collections took place in parts of Coastal Oregon, the Columbia River, and its tributaries (Downey et al. 1996; Close et al. 2004; Sheoships 2014). Further information on harvest is presented in Chapter 3 and Appendix 8. Pacific Lamprey are an important source of food, culture, and medicine to Native American tribes in Oregon (Close et al. 2002).

Euro-American settlers used Pacific Lamprey as bait for catching White Sturgeon (Mattson 1949), and "juveniles", "adult", and "lampreys" (species not identified) were used legally for bait for Northern Pikeminnow as recently as the 1990s (Nigro 1991; Nigro and Willis 1992; Willis et al. 1993; Willis and Young 1995; Young 1996, 1997, and 1998). Larval Pacific Lamprey have been used as bait for Smallmouth Bass in the John Day River (Close et al. 2002) and Umpqua River Basin (Ralph Lampman, Yakama Nation, pers. comm.), and this likely occurred elsewhere in Oregon. Pacific Lamprey were used for trapping fur-bearing mammals during the 1900s (Mattson 1949; Close et al. 2002). By about the early 1900s, aquaculturists were using raw, ground-up Pacific Lamprey to feed juvenile salmonids (Close et al. 2002). In 1913, 27 tons of adult Pacific Lamprey were harvested from Willamette Falls to provide feed for hatchery salmonids (Clanton 1913 — cited in Close et al. 2002). The first attempt at commercial harvest by Euro-American settlers of adult Pacific Lamprey occurred at the base of Willamette Falls in 1941 (Mattson 1949). Commercially-harvested Pacific Lamprey were processed for vitamin oil (presumably for human use), and protein for poultry and livestock feed or fertilizer (Mattson 1949). Harvest of Pacific Lamprey at Willamette Falls was most intense during the 1940s and 1950s, and has dropped sharply since then (Kostow 2002). Pacific Lamprey were also collected from Willamette Falls for teaching biology (i.e., North Carolina Biological Supply House), and for food outside of the United States: during 1994, nearly 2,000 kg of adult Pacific Lamprey were exported to Europe (Close et al. 2002).

Although no information is available specific to Western River Lamprey use by humans, they may have been used as bait for sportfish by anglers, similar to Pacific Lamprey and Western Brook Lamprey.

Larvae and adults of the Western Brook Lamprey were collected by anglers fishing for White Sturgeon in the Fraser River of British Columbia. Large larvae and recently transformed adult Western Brook Lamprey were used as bait for bass and trout anglers in Washington (Scott and Crossman 1973). Western Brook Lamprey may have been used in a similar fashion by anglers in Oregon, similar to Pacific Lamprey and Western Brook Lamprey. In addition to humans, many other animals prey on lampreys.

Predators, prey, and population cycles

The majority of information on predators of lampreys is for Pacific Lamprey, although some information exists for Western River Lamprey and Western Brook Lamprey. Cautious inferences may be made to fill in information gaps of predators of Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey if assumptions are made about the co-occurrence in time and space of these lampreys with particular predators (Table A3.4).

The caloric content of Pacific Lamprey is significantly higher than salmon (Close et al. 2002; Clemens et al. 2019), which may explain why they have been documented as prey by so many different animal species (Table A3.4). Several different fishes, including non-natives, consume larval lampreys (Table A3.4).

Pacific Lamprey and Western River Lamprey have been documented to depredate (parasitize) several different fishes and mammals in estuarine and marine environments (Table A3.5). Although it is often believed that predation by Pacific Lamprey occurs only in seawater, juvenile Pacific Lamprey have been documented to parasitize salmon smolts in the Snake River, approximately 391 river miles from the Pacific Ocean (Setter et al. 2004 — cited in Clemens et al. 2010). Similarly, lamprey marks have been documented on salmon smolts at John Day Dam, downstream in the mainstem Columbia River (Laurie Porter, CRITFC, pers. comm.). Western River Lamprey may begin parasitizing hosts in the freshwater or estuary (Beamish 1980). Both Pacific Lamprey and Western River Lamprey parasitize various species in the Columbia River estuary (Weitkamp et al. 2015).

Many data gaps exist for what, when, where, why, and how lampreys parasitize hosts (Beamish 1980; Clemens et al. 2010; Murauskas et al. 2013 and 2016; Wade and Beamish 2016). The available information (Table A3.5) could suggest that Pacific Lamprey and Western River

Lamprey are opportunistic and select prey based upon availability. Pacific Lamprey and Western River Lamprey prey on many of the same species, although some differences exist (Table A3.5). Pacific Lamprey are larger, tend to be more broadly distributed in the ocean, and spend longer periods in the ocean than Western River Lamprey (Tables 2.1 – 2.2). Pacific Lamprey prey on more species than Western River Lamprey, and no evidence of parasitization of Western River Lamprey has been observed on whales.

The co-occurrence of Pacific Lamprey with Walleye Pollock and Pacific Hake suggests these may be common prey items (see "Depth" section above); however, the extent of prey preference, prey killing, and prey switching is not well understood (Clemens et al. 2019). Some prey switching by Pacific Lamprey may occur as they grow as indicated by Pacific Lamprey wounds on Pacific Herring that are smaller than those on Walleye Pollock, and wounds on Walleye Pollock are smaller than those on Pacific Cod (Orlov et al. 2009). Wounding rates by Pacific Lamprey on Pacific Cod were most prevalent in relatively large Pacific Cod. Data on these wounds was used to infer that some mortality of Pacific Cod was caused by Pacific Lamprey (Siwicke and Seitz 2015). However, Pacific Lamprey wounds have been observed on adult Coho Salmon, Chinook Salmon, and steelhead passing Winchester Dam in the North Umpqua on their way to spawning grounds (ODFW unpubl. data), on 214 individual fish during 2003 – 2016, providing evidence that Pacific Lamprey can feed on hosts without killing them.

The relative abundance of Pacific Herring, Chinook Salmon, Pacific Cod, Walleye Pollock, and Pacific Hake in the Pacific Ocean are significantly associated with the abundance of adult Pacific Lamprey returning to the Columbia River Basin (Murauskas et al. 2013). This could suggest that adult Pacific Lamprey entering the Columbia River had previously migrated with their prey in the ocean north of the Columbia River mouth to feed on fish stocks off Vancouver Island, British Columbia. This could also suggest that Pacific Lamprey in the Bering Sea off Alaska and Russia may have originated from rivers in Canada and the U.S. (Murauskas et al. 2013). A connection between feeding grounds in the ocean and return migrations to Oregon has been demonstrated by a recent study by Murauskas et al. (2019). That study showed that a Pacific Lamprey tagged in the Bering Sea was subsequently detected at Bonneville Dam, and then again in the Deschutes River.

Western River Lamprey are found in surface waters of estuaries. This may influence their predatory habits of feeding in schools of Pacific Herring and on young salmon (Beamish 1980; Wade and Beamish 2016). Pacific Herring and young salmon are common prey for Western River Lamprey (Beamish 1980; Beamish and Neville 1995; Wade and Beamish 1986). A prey switch from salmon to Pacific Herring may occur in order of timing and appearance of these fishes in the Strait of Georgia (British Columbia; Beamish 1980). The voracious feeding habits of Western River Lamprey on their hosts suggests that they kill them. In the Strait of Georgia, Western River Lamprey is hypothesized to be a significant source of mortality for Pacific Herring and juvenile salmon (Beamish 1980; Beamish and Youson 1987; Beamish and Neville 1995). The abundance of Western River Lamprey appears to be associated with the abundance of Pacific Herring (Wade and Beamish 2016).

Abundance trends for Pacific Lamprey suggest decadal cycles of abundance, which may be attributed to their life span (Murauskas et al. 2013). Ocean survival of Pacific Lamprey may be limited by prey availability, which is influenced by environmental conditions. As such, prey availability may be a strong determinant of abundance of adult Pacific Lamprey and Western River Lamprey returning to freshwater (Murauskas et al. 2013; Wade and Beamish 2016). Many data gaps exist and the survival rate from larval to adult life stages is not known. A stock-recruit relationship has not been established for Pacific Lamprey (Clemens et al. 2017a) or other lampreys.

Table A3.4. Documented predators of lampreys. PL = Pacific Lamprey; WRL = Western River Lamprey; WBL = Western Brook Lamprey PBL = Pacific Brook Lamprey. E = Eggs; L = Larvae; J = Juveniles; A = Adults; NR = life stage not reported; – = lack of habitat overlap with predator suggests a low probability of predation. Unfilled cells = information lacking.

Predators		Study [e]	Origin	Habitat	PL	WRL	WBL/PBL
Fishes [a]	Salmon and trout	Field/Lab	Native	Freshwater	E, L	–	E, L, A
	Chinook	Lab	Native	Freshwater	L	–	
	Coho	Lab	Native	Freshwater		–	L
	Steelhead/Rainbow Trout	Field/Lab	Native	Freshwater	E, L	–	–
	Smallmouth Bass	Field/Lab	Non-native	Freshwater	L [f]	–	–
	Striped Bass	Field	Non-native	Freshwater/Seawater		NR	–
	Walleye	Field	Non-native	Freshwater	L, J [f]	L, J [f]	L, J [f]
	Channel Catfish	Field	Non-native	Freshwater	L, J	–	–
	Yellow Bullhead	Lab	Non-native	Freshwater	L	–	–
	Common Carp	Lab	Non-native	Freshwater	L	–	–
	Northern Pikeminnow	Field/Lab	Native	Freshwater	L, J	J, A [f]	–
	Chiselmouth	Lab	Native	Freshwater	L	–	–
	Speckled Dace	Field	Native	Freshwater	E	–	–
	Sculpin species	Field/Lab	Native	Freshwater	E, L	–	E
	White Sturgeon	Field/Lab	Native	Freshwater/Seawater	E, L, J, A	–	–
	Lingcod	Field	Native	Seawater	A	A	–
	Sablefish	Field	Native	Seawater	A	–	–
	Blue Shark	Field	Native	Seawater	A	–	–
	Bluntnose Sixgill Shark	Field	Native	Seawater	A	–	–
	Spiny Dogfish Shark	Lab	Native	Seawater	A	–	–
Reptiles [b]	Western Pond Turtle	Field	Native	Freshwater	A	–	–
Birds [c]	Raven	Lab	Native	Freshwater		–	A
	Great Blue Heron	Field	Native	Freshwater	A	–	–
	Osprey	Field	Native	Freshwater/Seawater	A	–	–
	Bald Eagle	Field	Native	Freshwater	A	–	–
	Caspian Tern	Field	Native	Freshwater/Seawater	L	L, A	–
	Forster's Tern	Lab	Native	Freshwater	L		–
	Double Crested Cormorant	Field	Native	Freshwater/Seawater	L, J	L, J	–
	Brandt's Cormorant	Field	Native	Freshwater/Seawater		A	–
	California Gull	Field	Native	Freshwater	L	–	A
	Ringbill Gull	Field	Native	Freshwater	L	–	A
	Western Gull	Field	Native	Freshwater/Seawater	L	–	–
Mammals [d]	American Mink	Field	Native	Freshwater	A	–	–
	River Otter	Field	Native	Freshwater	A	–	–
	Steller Sea Lion	Field	Native	Freshwater/Seawater	A	–	–
	California Sea Lion	Field	Native	Freshwater/Seawater	A	–	–
	Northern Elephant Seal	Field	Native	Seawater	A	?	–
	Northern Fur Seal	Field	Native	Freshwater/Seawater	A	–	–
	Pacific Harbor Seal	Field	Native	Freshwater/Seawater	A	A	–
	Sei Whale	Field	Native	Seawater	A	?	–
	Sperm Whale	Field	Native	Seawater	A	–	–

[a] Thomas (1967); Semakula and Larkin (1968); Scott and Crossman (1973); Beamish (1980); Harvey (1989); Close et al. (1995); Brumo (2006); Cochran (2009); Renaud (2011); Tinus (2012); Arakawa and Lampman (2017)

[b] Bury (1986) — Cochran (2009) surmised that the piece of adult Pacific Lamprey found in the turtle diet may have been scavenged.

[c] Merrell (1959); Wolf and Jones (1989); Close et al. (1995); Collis et al. (2002, 2006); Stillwater Sciences (2010); Zamon et al. (2014). Caspian Terns, Collis et al. (2002); Caspian Terns and Double Crested Cormorants, Don Lyons and Kirsten Bixler, Oregon State University, unpublished data. Lamprey were not identified to life stage or species in either of these studies, although "juveniles were assumed to constitute the diets of Caspian Terns and Double Crested Cormorants in the data from Lyons and Bixler. Lyons and Bixler also shared an image of Caspian Terns consuming a lamprey that looks to be about the size of a Western River Lamprey.

[d] Scott and Crossman (1973); Beamish (1980); Antonelis and Fiscus (1980); Condit and Le Boeuf (1984); Roff and Mate (1984); Flinn et al. (2002); Laake et al.(2002); Orr et al.(2004); Riemer et al. (2011); Wright et al. (2016); Stillwater Sciences (2010)

[e] This information does not necessarily indicates a preference, likelihood, or a particular frequency for predation in nature.

[f] Unpublished data from ODFW's Northern Pikeminnow Management Program.

Table A3.5. Documented prey of anadromous lampreys. Source information: Clemens and Wilby (1949); Pike (1951); Beamish (1980); Bond et al. (1983); Beamish and Neville (1995); Orlov et al. (2007, 2008b, 2009); Renaud (2011); Murauskas et al. (2013); and Weitkamp, et al. (NOAA Fisheries, unpubl. data).

Species	Pacific Lamprey	Western River Lamprey
Fishes		
Sockeye Salmon	X	X
Coho Salmon	X	X
Pink Salmon	X	X
Chinook Salmon	X	X
Chum Salmon		X
Steelhead	X	X [a]
Rougheye Rockfish	X	
Yellowmouth Rockfish	X	
Shortraker Rockfish	X	
Widow Rockfish	X	
Pacific Ocean Perch	X	
Pile surfperch		X
Shiner Perch		X
Pacific Cod	X	
Pacific Hake	X	
Walleye Pollock	X	
Lingcod	X	
Atka Mackerel	X	
Jack Mackerel	X	
Sablefish	X	
Northern Anchovy		X
American Shad		X
Pacific Herring	X	X
Greenland Halibut	X	
Pacific Halibut	X	
Arrowtooth Flounder	X	
Kamchatka Flounder	X	
Flathead Sole	X	
Petrale Sole	X	
Roughscale Sole	X	
English Sole		X
Bigfin Eelpout	X	
Western River Lamprey		X [b]
Pacific Lamprey		X [c]
Mammals		
Sei Whale	X	
Fin Whale	X	
Humpback Whale	X	
Sperm Whale	X	
Blue Whale	X	

[a] Identified from a single scale by Bond et al. (1983).

[b] Unclear whether feeding occurred on live or dead Western River Lamprey (Beamish 1980).

[c] Unclear whether feeding occurred on live or dead Pacific Lamprey, per Beamish (1980).

Appendix 4. Comparison of management units and limiting factors

Partners in the Pacific Lamprey Conservation Initiative (PLCI; Chapter 1) created Regional Management Units (RMUs) for Pacific Lamprey and identified threats and limiting factors for this species, within these RMUs. This appendix compares these RMUs with ODFW's population strata (Table A4.1). This appendix also compares ODFW's limiting factors with the PLCI's threats and limiting factors (Tables A4.2 – A4.3). The PLCI's threats and limiting factors were reported by 4th field Hydrologic Unit (HUC; USFWS 2018). The "scope" and "severity" of limiting factors identified by the PLCI were averaged to create one score per limiting factor for each 4th field HUC. These scores were averaged for all 4th field HUCs within a particular stratum. Chapter 5 provides details on how the scores for limiting factors were combined with ODFW's assessment of limiting factors to result in the final ranking of limiting factors (Table 5.2).

Table A4.1. Comparison of population strata used by ODFW for management and research of Pacific Lamprey, Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey, and RMUs used by the PLCI for management and research of Pacific Lamprey.

Population strata (ODFW)	Regional Management Units (USFWS)
–	North Pacific Ocean
Coastal; Rogue/South Coast	North and South Coast Oregon
Lower Columbia	Lower Columbia/Willamette; Mid-Columbia
Willamette	Lower Columbia/Willamette
Mid Columbia	Mid-Columbia
Lower Snake; Upper Snake	Snake

Table A4.2. Limiting factors considered for lampreys. Note that limiting factors may occur at various spatial (e.g., freshwater, estuary, ocean) and temporal (larval, juvenile, adult) points within the lamprey life cycle. The right-hand column indicates the crosswalk with the PLCI (Table A4.3).

Management Category	Limiting Factor	Description	Comparison with PLCI (Table A4.3)
Water Quality	Temperature	***See Table 5.1***	4, 10, 11
	Sedimentation		
	Toxic Pollutants		
	Other		
Water Quantity	Low	***See Table 5.1***	2, 11
	Altered Hydrology		
Habitat Access (Passage)	Inundation	***See Table 5.1***	1
	Upstream Passage		
	Downstream Passage		
Physical Habitat	Instream Structure	***See Table 5.1***	3, 11
	Substrate		
	Peripheral Connection		
Other Species	Predation	***See Table 5.1***	6, 10, 11
	Competition	***See Table 5.1***	Not applicable
	Hybridization		
	Food Source	***See Table 5.1***	10, 11
	Disease	***See Table 5.1***	7, 11
	Other	***See Table 5.1***	11
Direct Interaction	Release	***See Table 5.1***	6, 7
	Take [a]	***See Table 5.1***	5, 8

[a] This description of "take" is for limiting factor consideration, and is not the same as the legal definition of "take" found in Oregon's statutes and administrative rules.

Table A4.3. Threats and limiting factors for Pacific Lamprey identified by the PLCI (USFWS 2018). Numbering of the limiting factors and threats is used to associate with limiting factors in Table A4.2 and does not necessarily indicate the priority in Oregon.

Threats and limiting factors
1. Passage
2. Dewatering / stream flow management
3. Stream & floodplain degradation
4. Water quality
5. Harvest/overuse
6. Predation
7. Disease
8. Small effective population size
9. Lack of awareness
10. Ocean conditions
11. Climate change

Appendix 5. Supporting information for assessing distribution

This appendix presents details on the Methods, Results, and Conclusions for SDMs that were used to assess current distribution in population strata (Chapter 3) and future distribution (Chapter 5) for Pacific Lamprey. The main conclusions can be found in chapters 3 and 5.

SPECIES DISTRIBUTION MODELS

Species distribution models are defined as models that relate species distributional data (occurrence, abundance) at a particular location with information on the environmental conditions at that location (Elith and Leathwick 2009). Current distribution maps only convey where a species is expected to occur under current conditions. By contrast, SDMs can be used to: 1) explain relationships between species and habitat, 2) predict distribution in locations lacking data, and 3) predict distribution under different environmental conditions. The probability of occurrence can be interpreted as habitat suitability or availability depending on habitat accessibility. Like all modeling approaches, a number of assumptions and uncertainties are necessary when using SDMs. Prominent assumptions specific to SDMs are: 1) species occurrence data are always incomplete, 2) imperfect knowledge of the factors driving occurrence, 3) species-environment relationships are flexible, and 4) if considering future climate scenarios, uncertainty exists among model predictions (based on emission assumptions; Wenger et al. 2013). Thus SDMs should be treated as a hypothesis to test and validate. Additional sampling and modeling should be conducted to improve an SDM; in this way developing SDMs is an iterative process (Jarnevich et al 2015). SDMs have the potential to guide future field surveys, inform the classification of species habitat, identify habitat restoration or protection opportunities, and inform management.

METHODS

POPULATION STRATA AND DATASETS

Adequate data were available to develop SDMs for Pacific Lamprey for four strata: 1) Rogue/South Coast, 2) Coastal, 3) Lower Columbia, and the 4) Willamette (Figure A5.1A). Species occurrence data originated from several sources that used different survey methods (Table A5.1). Adult Pacific Lamprey were targeted because data was more prevalent for this life stage. A large percentage of the data originated from ODFW projects (Table A5.1). Specifically, a targeted sampling of spawning lamprey by ODFW's Oregon Adult Salmonid Inventory and Sampling (OASIS program) contributed the majority of data. This data included presence/absence of adults, carcasses, and redds (Jacobsen et al. 2014, 2015; Brown et al. 2017). The second most abundant dataset originated from the presence/absence of species within fish community sampling from the U.S. Environmental Protection Agency's (EPA), Environmental Monitoring and Assessment Program (EMAP; Mims et al. 2018; Herlihy et al. 2006; Table A5.1).

Table A5.1. Occurrence datasets for Pacific Lamprey.

Data Source	Collection Method	Years	Number surveys
ODFW's OASIS Project	Random surveys	2007 – 2016	1,331
Oregon EMAP (Herlihy et al. 2006)	Fish assemblage	1997 – 2001	119
Regional EMAP (Herlihy et al. 2006)	Fish assemblage	1994 – 2001	33
ODFW Native Fish Program	Fish assemblage	2014	23
National Water-Quality Assessment Program	Fish Assemblage	1994 – 2001	20
Western EMAP (Herlihy et al. 2006)	Fish assemblage	1994 – 2001	7

Only data with unambiguous species identification and data collected after 1990 were included in the analyses. The 1990 date was chosen for three reasons. First, this date was recommended by ODFW biologists working with species occurrence records. Second, most of the occurrence data were collected after this year. Third, this matched the time frame for the temperature and hydrologic data used in the modeling.

All occurrence sites were georeferenced on the 1:100,000k scale National Hydrography Dataset (NHD) that had been pre-conditioned in order to use the STARS toolbox within ArcGIS (Peterson and Ver Hoef 2014). Using the STARS toolbox, upstream distance was calculated from the stream outlet (e.g. the most downstream location in the stream network) to each stream reach for all lamprey occurrence sites. Associating occurrence sites with individual NHD reaches was necessary so the final model could be used to predict to NHD stream reaches where occurrence sites did not occur.

Predictor variables were selected based on hypothesized effects on lamprey occurrence. Most predictor variables are time-invariant, with the exception of stream temperature and stream flow. Historical and projected stream temperature was obtained from the NorWeST dataset (Figure A5.2; Isaak et al. 2017). Stream flow estimates originated from the Variable Infiltration Capacity (VIC) dataset (Figures A5.3 – A5.5). Daily runoff and base flow values from the VIC macroscale hydrologic model were used to estimate historical and projected future stream flow metrics for stream segments in the Western U.S. (Gao et al. 2010; Wenger et al. 2010). The following three variables were evaluated: 1) mean summer flow, 2) the number of daily flows in winter exceeding 95th percentile of daily flows across year (W95), and 3) the center of flow mass (CFM; the day of the year when most precipitation leaves a basin as streamflow). In a flashy system where precipitation always falls as rain and little of it percolates to groundwater, flows spike and recede quickly and the CFM would be low. In a snow-dominated system or one with large groundwater influence, precipitation would drain more slowly and later in the water year and the CFM would be high. The August stream temperature dataset was the most complete, and so this was used in SDMs.

Models were built for stream temperature and stream flow variables using the native historical time periods in each dataset (NorWeST 1993 – 2011; VIC 1930 – 2001). Both the NorWeST and VIC datasets incorporate climate scenarios based on global model projections using the ensemble mean of the 10 climate models developed by the Intergovernmental Panel on Climate Change (IPCC). These models represent the “A1B” greenhouse gas emissions trajectory for the 2040s (2030 – 2059) and 2080s (2070 – 2099; Isaak et al. 2017). These scenarios were used when evaluating future projections of the distribution of Pacific Lamprey.

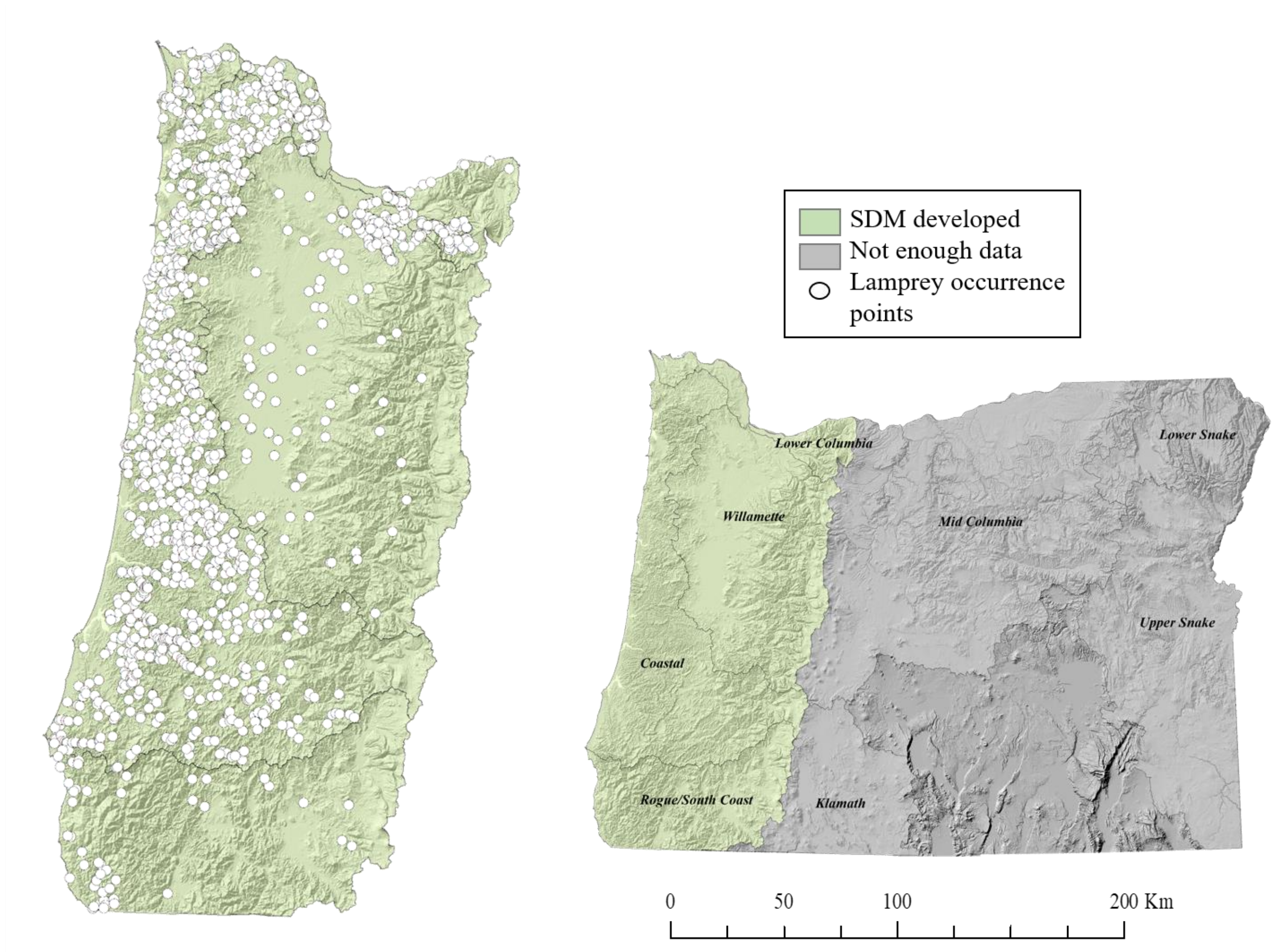

Figure A5.1. Population strata (including the Rogue/South Coast, Coastal, Lower Columbia, and Willamette) and occurrence data used in modeling distribution for Pacific Lamprey. Regions shaded green contained enough data to develop SDMs. Regions shaded grey contained insufficient data to develop SDMs.

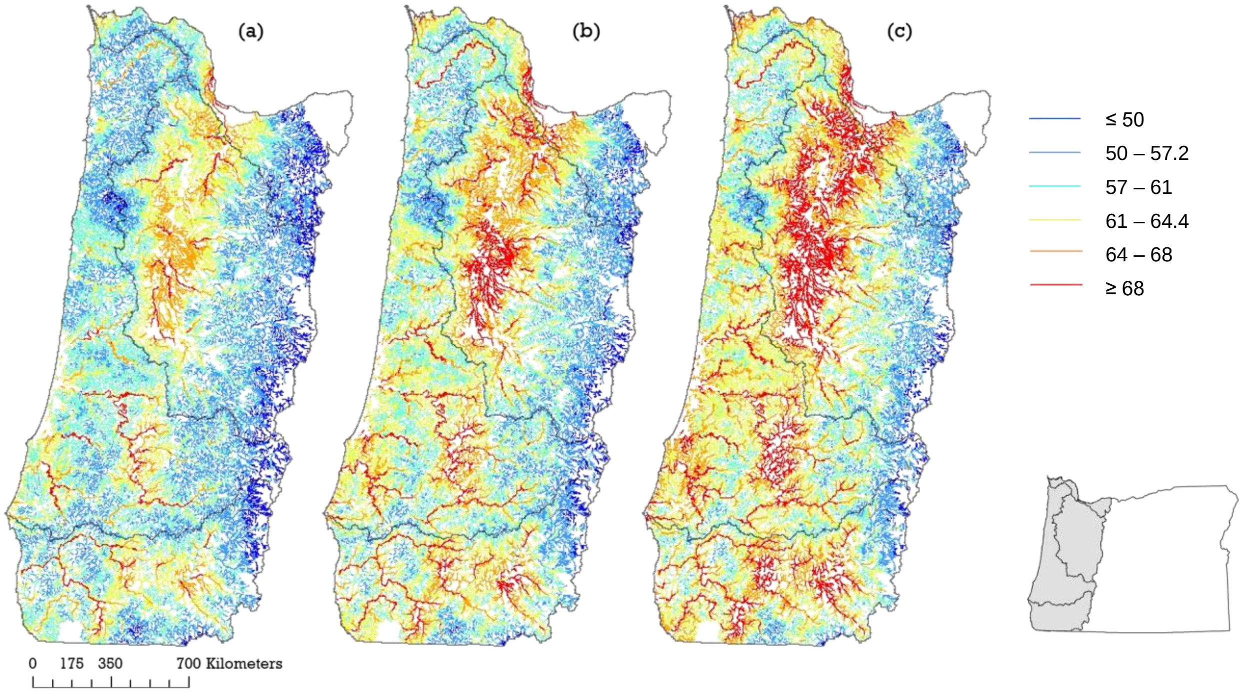

Figure A5.2. NorWeST August stream temperature estimates (°F) for Western Oregon (Isaak et al. 2017), (**A**) native historical (1993-2011), (**B**) 2040 projection, and (**C**) 2080 projection. Oregon subset shows the state boundary with the four PS included in this analysis.

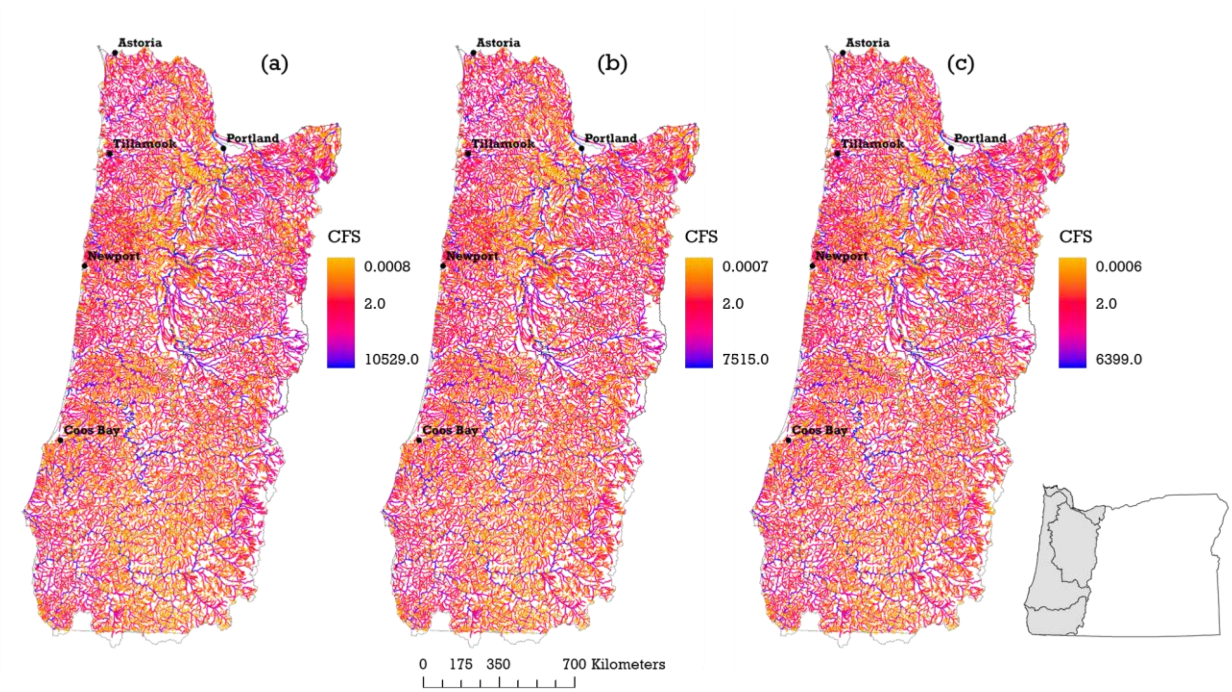

Figure A5.3. Variable Infiltration Capacity dataset: mean summer stream flow data (cubic feet per second) for Western Oregon (Gao et al. 2010), (**A**) native historical 1930-2001 stream flow estimate, (**B**) difference between historical and 2040 projection, and (**C**) difference between historical and 2080 projection. Oregon subset shows the state boundary with the four PS included in this analysis.

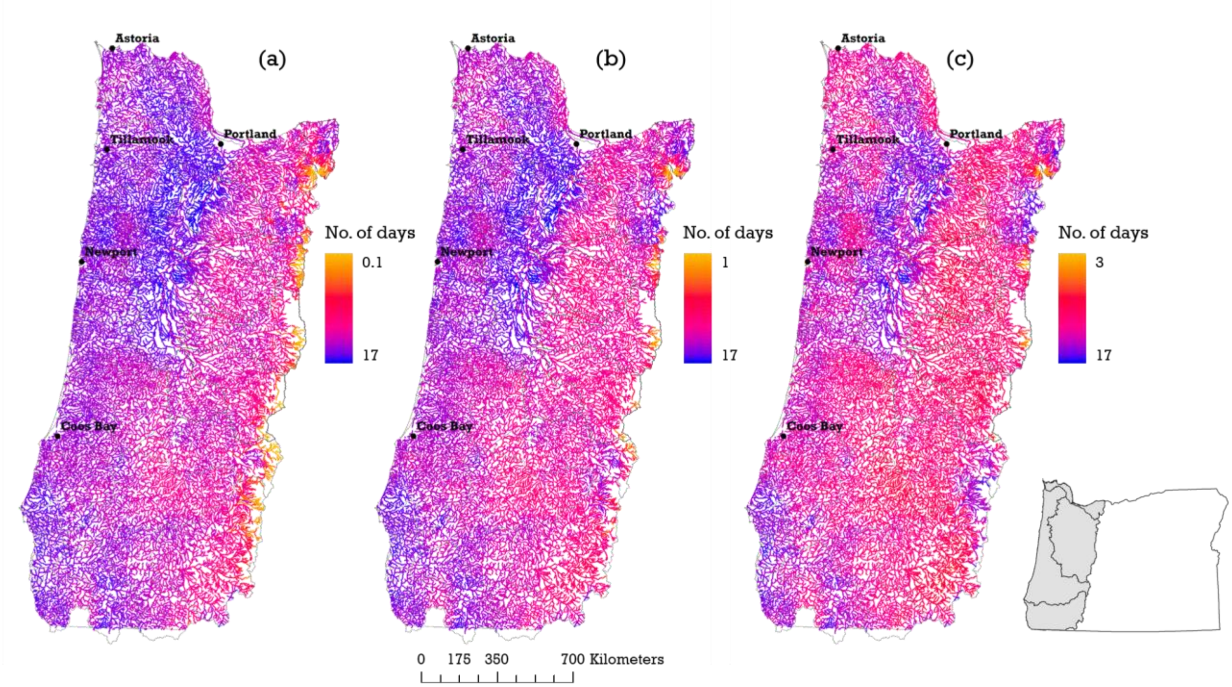

Figure A5.4. Variable Infiltration Capacity dataset: winter flow estimates (number of days exceeding 95th percentile of flows) for Western Oregon (Gao et al. 2010), (**A**) native historical 1930 – 2001, (**B**) 2040 projection, and (**C**) 2080 projection. Oregon subset shows the state boundary with the four PS included in this analysis.

Several additional predictor variables were evaluated. Predictor variables for lithology, land cover, and disturbance (Figures A5.6 – A5.7) were obtained from the Stream-Catchment (StreamCat) dataset, which has been summarized for individual stream catchments and cumulative upstream watersheds based on the NHD Plus Version 2 geospatial framework (Hill et al. 2016). A number of lithology variables were assessed. However, only non-carbonate lithology was included because it is distributed throughout Western Oregon (Table A5.2; Figure A5.6). Stream slope, upstream distance (Table A5.2) and stratum (Rogue/South Coast, Coastal, Lower Columbia, and Willamette) were also included (Figure A5.1; Table A5.2). Artificial obstructions were considered for inclusion into the SDMs. These barriers can impede upstream passage of adult Pacific Lamprey, and this conservation plan recognizes artificial obstructions as a primary limiting factor for this species (Chapter 5). However, artificial obstructions were not included as predictor variables for two reasons: 1) barrier counts are inconsistent across strata and 2) the uncertainty in extent of passage possible by Pacific Lamprey (e.g., blocked, partially-blocked, flow-dependent passage) for each artificial obstruction. Artificial obstructions will be considered for inclusion in a future, updated version of the SDM.

MODELING METHOD

Logistic regression was used to model the probability of lamprey occurrence throughout Western Oregon. Multicollinearity among predictor variables was evaluated for the global model using the variable inflation factor (car v3.0-0 R package, Fox and Weisberg 2011) and the variable importance statistic (caret R package, Kuhn et al. 2017). When comparing two collinear variables, the variable with higher importance (based on the variable importance statistic) was retained.

Table A5.2. Independent predictor variables considered in SDMs for Pacific Lamprey. VIC = variable infiltration capacity.

Variable name	Variable description	Data source
Stream flow (historical)	Mean summer flow (cfs)	VIC
Winter flow (native historical)	Number of daily flows during Dec 1 – Mar 31 > 95th percentile of daily flows across entire year	VIC
Center of flow (native historical)	Day of the water year with the center of flow mass. Measures when the majority of precipitation leaves a basin as stream flow. Daily flow observations or flow estimates are multiplied by the day of the water year and summed.	VIC
Stream flow (projection)	Mean monthly temperature from best model: 2030 – 2059 (2040) 2070 – 2099 (2080)	VIC
Stream temperature (native historical)	Mean monthly August temperature 1993 – 2011	NorWeST (Isaak et al. 2017)
Stream temperature (projection)	Mean monthly temperature from best model: 2030 – 2059 (2040) 2070 – 2099 (2080)	NorWeST (Isaak et al. 2017)
Stream slope	Stream slope (%)	NHD Plus attributes
Conifer cover	Conifer land cover (% within the catchment)	StreamCat; Hill et al. (2016)
Impervious surface	Mean imperviousness of human-made surfaces (% within catchment)	StreamCat; Hill et al. (2016)
Lithology	Non-carbonate residual (% within catchment)	StreamCat; Hill et al. (2016)
Upstream distance	Upstream distance	Calculate in ArcMap 10.5
Road-stream crossings	Density of road–stream intersections within the catchment (N/A)	StreamCat; Hill et al. 2016

Prior to modeling, the occurrence dataset was split into a training dataset (90% random subset of the original data) and a test dataset (10% random subset of the original dataset). The model was trained on the training dataset using logistic regression. The final, fitted candidate model(s) were then used to predict the responses in the test dataset. This provided an unbiased evaluation of the model fit because the test dataset is independent of the training dataset, but presumably follows the same probability distribution. This is common practice and a fundamental tool in machine learning.

Thirty logistic regression candidate models were developed, including the null model, using environmental variables hypothesized to influence the distribution of Pacific Lamprey. Three types of models were considered during model development: 1) simple, temperature and flow only models, 2) the full, global model excluding interactions and polynomial relationships, and 3) models containing both polynomial terms and/or interactions. Models with and without the population stratum (i.e., geographical region) categorical variable were evaluated to determine whether its inclusion improved model fit. Quadratic polynomial terms were evaluated to see if including them improved model fit. Quadratic polynomial terms for the mean August temperature, mean summer flow, winter flow and center flow predictors were evaluated. These variables were hypothesized to not have a strictly linear relationship with the occurrence of lamprey. Interaction terms between population stratum and the same four predictor variables were also included in the models to evaluate whether the relationship between occurrence and stream temperature or stream flow varied as a result of the categorical variable, population stratum.

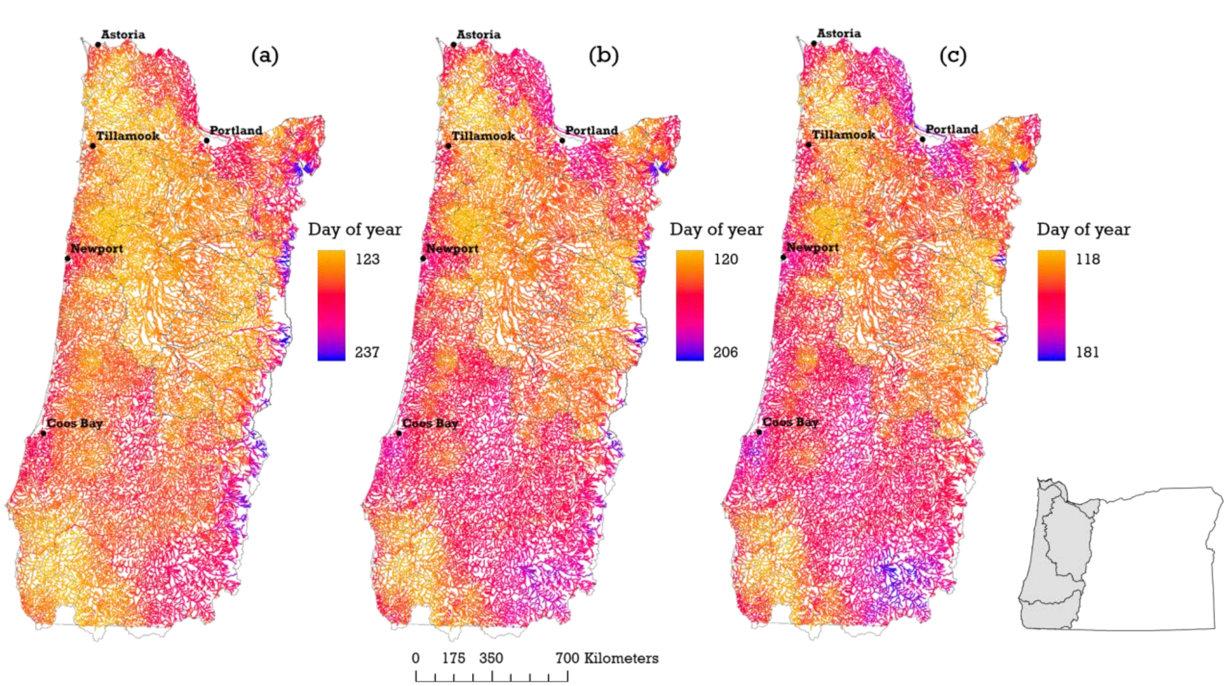

Figure A5.5. Variable infiltration capacity center of flow mass (day of the year) for Western Oregon (Gao et al. 2010), (**A**) native historical 1930 – 2001, (**B**) 2040 projection, and (**C**) 2080 projection. Oregon subset shows the state boundary with the four PS included in this analysis.

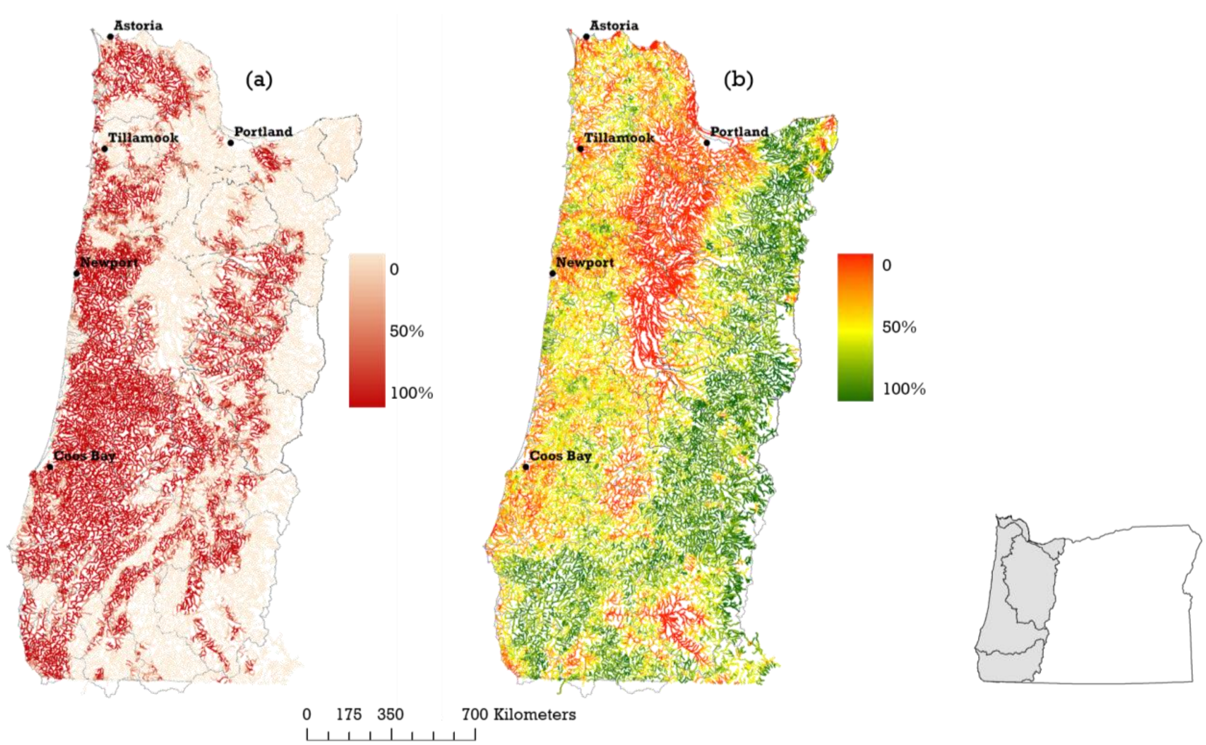

Figure A5.6. Lithology and land cover geospatial data used in modeling (StreamCat; Hill et al. 2016); (**A**) percent non-carbonate lithology and (**B**) percent conifer land cover. Oregon subset shows the state boundary with the four PS included in this analysis.

Logistic regression models were evaluated using Akaike Information Criterion (AIC) values and Akaike weights (Burnham and Anderson 2002) in order to assess the ability of each model to support the data. Akaike weights represent the relative likelihood of a model. Model(s) with delta (Δ) AIC values (the difference between a particular model and the model with the lowest AIC value) ≤ 3 were considered to have substantial support and were retained.

Model validation was conducted for the candidate models and the null model. Two different methods were used to assess model accuracy: area under the curve (AUC) statistics using the predicted scores to determine the optimal cut-off and cross-validation statistics. For the cross validation statistics, k-fold cross validation with 10 random subsets or "folds" was used. Both mean square error (MSE) and the rate of misclassification were evaluated, and the model with the highest accuracy was used for prediction. The "InformationValue" package in R was used to evaluate model validation (Prabhakaran 2016). Additionally, two threshold-dependent indices were calculated to evaluate accuracy. Sensitivity is defined as the probability that the model correctly predicts an observation at a site while specificity is the probability that a known absence is correctly predicted.

Predictions were developed for the final, selected species distribution model. The first was under current or baseline conditions which referenced the time period of the occurrence data used (1994 – 2016). This time period also approximately corresponded to the native historical period from which the hydrologic and temperature variables were developed. For forecasts under future climate conditions, we used projected hydrologic and temperature conditions in the 2040s and 2080s available from the NorWest and VIC datasets.

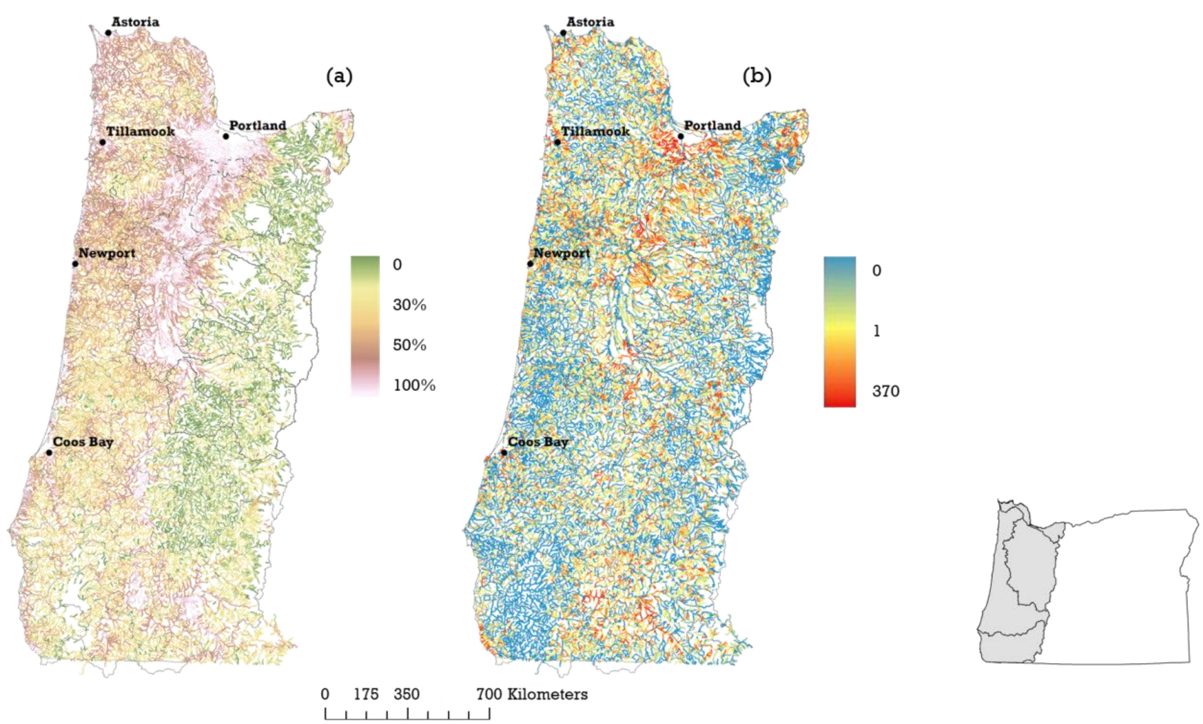

Figure A5.7. Disturbance geospatial data used in modeling (StreamCat; Hill et al. 2016): (**A**) percent impervious surface and (**B**) road-stream intersections. Oregon subset shows the state boundary with the four PS included in this analysis.

RESULTS

A total of 1,539 sites (Table A5.3) were used to develop the distribution models for Pacific Lamprey. Twenty-seven candidate SDMs for Pacific Lamprey were evaluated (Table A5.4). Of these, only three showed substantial empirical support (ΔAIC ≤ 3.0; Table A5.5). The best-supported model, "Augfm15" (Table A5.4), had 48.4% weight and included slope, upstream distance, stratum, mean August stream temperature, mean summer stream flow, winter flow, and center of flow mass (Table A5.5). Additionally, there was support for interaction terms between stratum and mean summer flow, center of flow, and mean August temperature. This model included quadratic polynomials for stream temperature, center of flow, and winter flow. The next best-supported model, "Augfm16", was a similar model, including additional predictor variables percent impervious surface and road crossings. The third best-supported model, "Augfm27", was the same model as "Augfm16" excluding the quadratic terms (Tables A5.4 and A5.5). Given similar model accuracies (Table A5.6), the simpler model ("Augfm27") was chosen. Descriptive statistics for all independent predictor variables in the final model can be found in Table A5.3. The mapped probabilities of occurrence are shown in Table 5.3 (Chapter 5) and Figure A5.9 and response curves are shown in Figure A5.8. The estimates are presented as odds ratios because the models were on the logit scale. To facilitate interpretation Table A5.7 shows the simple slopes for each of the interaction terms. A simple slope is the regression of the outcome of the response (occurrence) on the predictor (e.g. mean August temperature) at specific value of the moderator (population stratum).

Table A5.3. Descriptive statistics for occurrence datasets and predictor variables included in the final distribution model for Pacific Lamprey, N=1,539. Population stratum abbreviations: RSC = South Coast; CST = Coastal; LC = Lower Columbia; WI = Willamette.

Variable	Strata	N per strata	Mean	Median	Minimum	Maximum
Occurrence	2	Absence (0) = 767; Presence (1) = 772				
Population stratum	4	LC = 422; WI = 108; CST = 961; RSC = 48				
Slope (m/m)			0.026	0.014	0.000	0.249
Upstream distance (km)			23.756	18.041	0.107	122.775
Winter flow exceedance 95th (no. days)			14.503	14.897	3.103	17.138
Mean summer flow (cfs)			72.251	7.690	0.052	4,459.262
Center of flow mass (day of water year)			143.90	143.50	126.10	196.00
Mean August temperature (°C)			15.140	14.910	7.050	23.570
Percent impervious surface			1.231	0.350	0.000	49.997
Road-stream intersections (density)			0.425	0.283	0.000	10.752

The final model had an accuracy of 81% based on the AUC statistic, with a misclassification error of 0.24. The model had a sensitivity (true positive rate) value of 0.756 and specificity (true negative rate) value of 0.694. For baseline conditions, mean estimates of occurrence ranged from zero to near one. The model predicted higher mean occurrence probabilities for the Coastal stratum. For all strata, occurrence probabilities were highest in stream segments with lower slopes, lower impervious surface percentages, and in locations with larger distances from the ocean. Where interactions were supported, different responses among strata are evident (Tables A5.7 and A5.8). The probability of occurrence of Pacific Lamprey tended to increase as mean summer flow increased in the Rogue/South Coast, Coastal, and Lower Columbia strata. However, only the interaction with the Coastal stratum was significant at a 0.05 alpha level. With the exception of the Willamette stratum, the probability of occurrence of Pacific Lamprey decreased as the center of the flow mass decreased in all strata (although only the interaction in the Lower Columbia was significant). Finally, the probability of occurrence increased with decreasing mean August temperatures in all strata except the Lower Columbia (Tables A5.7 and A5.8; Figures A5.8 – A5.9).

When evaluating the probability of occurrence under future, projected conditions, different conditions emerge across strata. The distance of suitable habitat predicted under current (baseline), 2040, and 2080 conditions was evaluated. The proportional change from current to 2080 was calculated when suitability was defined as a probability of occurrence ≥ 50% and a probability of occurrence ≥ 80% (Table 5.3; Figure A5.9). In both cases, the distance of suitable habitat declines from current conditions to the 2040s and 2080s. The model predicted the largest decline in the Willamette followed by the Lower Columbia when probability of occurrence was ≥ 50%. When looking at stream segments with ≥ 80% probability of occurrence, the model predicted the largest decline in the Lower Columbia.

Table A5.4. Names of SDMs that were assessed for Pacific Lamprey and the predictor variables associated with these models. PS represents the population strata: Lower Columbia, Coastal, Willamette, and Rogue/South Coast.

Model name	Predictor variables
null	PA ~ 1
tempOnly	PA ~ PS + Mean August Temp. + PS* Mean August Temp.
flowOnly1	PA ~ PS + Mean Summer Flow + PS* Mean Summer Flow
flowOnly2	PA ~ PS + Winter Flow + PS* Winter Flow
flowOnly3	PA ~ PS + Center of Flow + PS* Center of Flow
flowOnly4	PA ~ PS + Winter Flow + PS* Winter Flow + Center of Flow + PS* Center of Flow
flowOnly5	PA ~ PS + Mean Summer Flow + PS* Mean Summer Flow + Winter Flow + PS* Winter Flow + Center of Flow + PS* Center of Flow
flow_temp	PA ~ PS + Mean Summer Flow + PS* Mean Summer Flow + Winter Flow + PS* Winter Flow + Center of Flow + PS* Center of Flow + Mean August Temp. + PS* Mean August Temp.
Augfm1	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Center of Flow + Mean August Temp. + Pct. Conifer + Pct. Impervious + Pct. Non-Carbonate + Road-Stream crs
Augfm2	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Center of Flow + Mean Summer Flow + PS* Mean August Temp.
Augfm3	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Mean Summer Flow + Center of Flow + PS* Mean Summer Flow
Augfm4	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Mean Summer Flow + Center of Flow + PS*W95_Hist
Augfm5	PA ~ Slope + Upstream distance + PS + Mean August Temp + Winter Flow + Mean Summer Flow + Center of Flow + PS* Center of Flow
Augfm6	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Mean August Temp. + Center of Flow + PS* Winter Flow + PS* Mean Summer Flow
Augfm7	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Mean August Temp. + Center of Flow + PS* Winter Flow + PS* Center of Flow
Augfm8	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Mean August Temp. + Center of Flow + PS* Mean August Temp. + PS* Center of Flow
Augfm9	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Mean August Temp. + Center of Flow + PS* Mean August Temp. + PS* Winter Flow + PS* Center of Flow + PS* Mean Summer Flow
Augfm10	PA ~ Slope + Upstream distance + PS
Augfm11	PA ~ Slope + Upstream distance + PS + Mean Summer Temp. + Mean Summer Flow + Center of Flow + Center of Flow_poly
Augfm12	PA ~ Slope + Upstream distance + PS + Mean August Temp + Mean August Temp_poly + Winter Flow + Winter Flow_poly + Center of Mean Summer Flow + Center of Flow_poly
Augfm13	PA ~ Slope + Upstream distance + PS + Mean August Temp + Mean August Temp_poly + Mean Summer Flow + Winter Flow + Winter Flow_poly + Center of Flow + Center of Flow_poly + PS* Center

	of Flow + PS* Center of Flow_poly
Augfm14	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Winter Flow_poly Mean Summer Flow + Center of Flow + Center of Flow_poly + PS* Mean August Temp.
Augfm15	PA ~ Slope + Upstream distance + PS + Mean August Temp + Mean August Temp._poly + Winter Flow + Mean Summer Flow + Center of Flow + PS* Mean August Temp. + PS*Center of Flow + PS*Center of Flow _poly + PS*Mean Summer Flow
Augfm16	PA ~ Slope + Upstream distance + PS + Mean August Temp + Mean August Temp._poly + Winter Flow + Mean Summer Flow + Center of Flow + PS* Mean August Temp._poly + PS*Center of Flow + PS*Center of Flow_poly + PS*Mean Summer Flow + Pct. Impervious + Road-Stream crs
Augfm17	PA ~ Slope + Upstream distance + PS + Mean August Temp + Mean August Temp._poly + Winter Flow + Winter Flow_poly + Mean Summer Flow + Center of Flow + Center of Flow_poly + PS*Center of Flow + PS*Center of Flow_poly + PS*Mean August Temp + PS*Mean August Temp_poly + + Pct. Impervious + Pct. Non-Carbonate + Road-Stream crs
Augfm18	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Mean Summer Flow + Center of Flow + PS* Mean August Temp. + Pct. Impervious + Pct. Non-Carbonate + Road-Stream crs
Augfm19	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Mean Summer Flow + Center of Flow + PS*Center of Flow + Pct. Conifer + Pct. Impervious + Pct. Non-Carbonate + Road- Stream crs
Augfm20	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Mean Summer Flow + Center of Flow + PS* Mean August Temp. + PS*Center of Flow + Pct. Conifer + Pct. Non-Carbonate + Pct. Impervious + Road-Stream crs
Augfm21	PA ~ Slope + Upstream distance + PS + Mean August Temp.+ Winter Flow + Mean Summer Flow + Center of Flow + PS*Center of Flow + Pct. Conifer + Pct. Impervious + Road-Stream crs
Augfm22	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Center of Flow + Mean August Temp. + PS* Mean August Temp. + Pct. Impervious + Pct. Non-Carbonate + Road-Stream crs
Augfm23	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Center of Flow + Mean August Temp. + PS*Center of Flow + Pct. Conifer + Pct. Non-Carbonate + Pct. Impervious + Road- Stream crs
Augfm24	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Center of Flow + Mean August Temp. + PS* Center of Flow + Pct. Impervious + Road-Stream crs
Augfm25	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Center of Flow + Mean August Temp. + PS*Center of Flow + PS*Mean August Temp. + PS*Winter Flows + Pct. Impervious + Road-Stream crs
Augfm26	PA ~ Slope + Upstream distance + PS + Winter Flow + Mean Summer Flow + Center of Flow + Mean August Temp. +PS*Winter Flows + PS*CFM Center of Flow + PS* Mean August Temp. + Road- Stream crs
Augfm27	PA ~ Slope + Upstream distance + PS + Mean August Temp. + Winter Flow + Mean Summer Flow + Center of Flow + PS* Mean Summer Flow + PS*Mean August Temp. + PS*CFM Center of Flow + Pct. Impervious + Road-Stream crs

Table A5.5. Final candidate SDMs for Pacific Lamprey. Models are ranked in order of their Δ Akaike Information Criterion (AIC). To see individual variables included in each model, see Table A5.3.

Model name	K	AIC	ΔAIC	AICWt
Augfm15	28	1,633.918	0.000	0.485
Augfm16	30	1,634.848	0.930	0.305
Augfm27	21	1,635.837	1.918	0.186
Augfm12	13	1,641.432	7.514	0.011
Augfm9	22	1,643.197	9.279	0.005
Augfm6	16	1,643.692	9.774	0.004
Augfm24	18	1,645.195	11.277	0.002
Augfm14	25	1,646.035	12.117	0.001
Augfm23	19	1,647.185	13.267	0.001
Augfm11	12	1,648.256	14.338	0.000
Augfm25	21	1,648.419	14.501	0.000
Augfm20	20	1,649.034	15.116	0.000
Augfm17	29	1,649.784	15.866	0.000
Augfm21	16	1,650.345	16.427	0.000
Augfm13	18	1,651.805	17.887	0.000
Augfm19	17	1,651.833	17.915	0.000
Augfm5	13	1,652.558	18.639	0.000
Augfm4	13	1,652.609	18.690	0.000
Augfm26	20	1,655.375	21.457	0.000
Augfm22	16	1,656.859	22.941	0.000
Augfm18	17	1,658.553	24.635	0.000
Augfm2	13	1,660.438	26.520	0.000
Augfm3	13	1,666.441	32.523	0.000
Augfm1	14	1,667.208	33.289	0.000
Augfm8	15	1,671.384	37.466	0.000
Augfm7	15	1,674.875	40.957	0.000
flow_TempOnly	20	1,680.518	46.600	0.000
flowOnly5	16	1,682.871	48.953	0.000
Augfm10	6	1,715.921	82.003	0.000
flowOnly1	8	1,780.910	146.992	0.000
flowOnly4	12	1,852.281	218.363	0.000
flowOnly3	8	1,854.199	220.280	0.000
tempOnly	8	1,864.692	230.773	0.000
flowOnly2	8	1,867.754	233.836	0.000
null	1	1,922.000	288.081	0.000

Table A5.6. Validation statistics for SDMs evaluated for Pacific Lamprey. Two different methods were used: area under the curve (AUC) statistics using the predicted scores to determine the optimal cut-off and cross-validation statistics. For cross validation statistics, k-fold cross validation (k-fold10 CV) with 10 random subsets or "folds" were used, employing the training and testing dataset. The "null" model includes only the intercept. See Table A5.3 for model names and predictor variables. NA = not applicable.

Model	Accuracy (AUC)	Accuracy (mis-classification error)	k-fold10 CV (mean)	Sensitivity (true positive rate)	Specificity (true negative rate)
August15	0.817	0.233	0.737	0.495	0.779
August16	0.816	0.246	0.776	0.714	0.766
August 27	0.815	0.240	0.783	0.714	0.779
Null	0.500	0.468	0.470	NA	NA

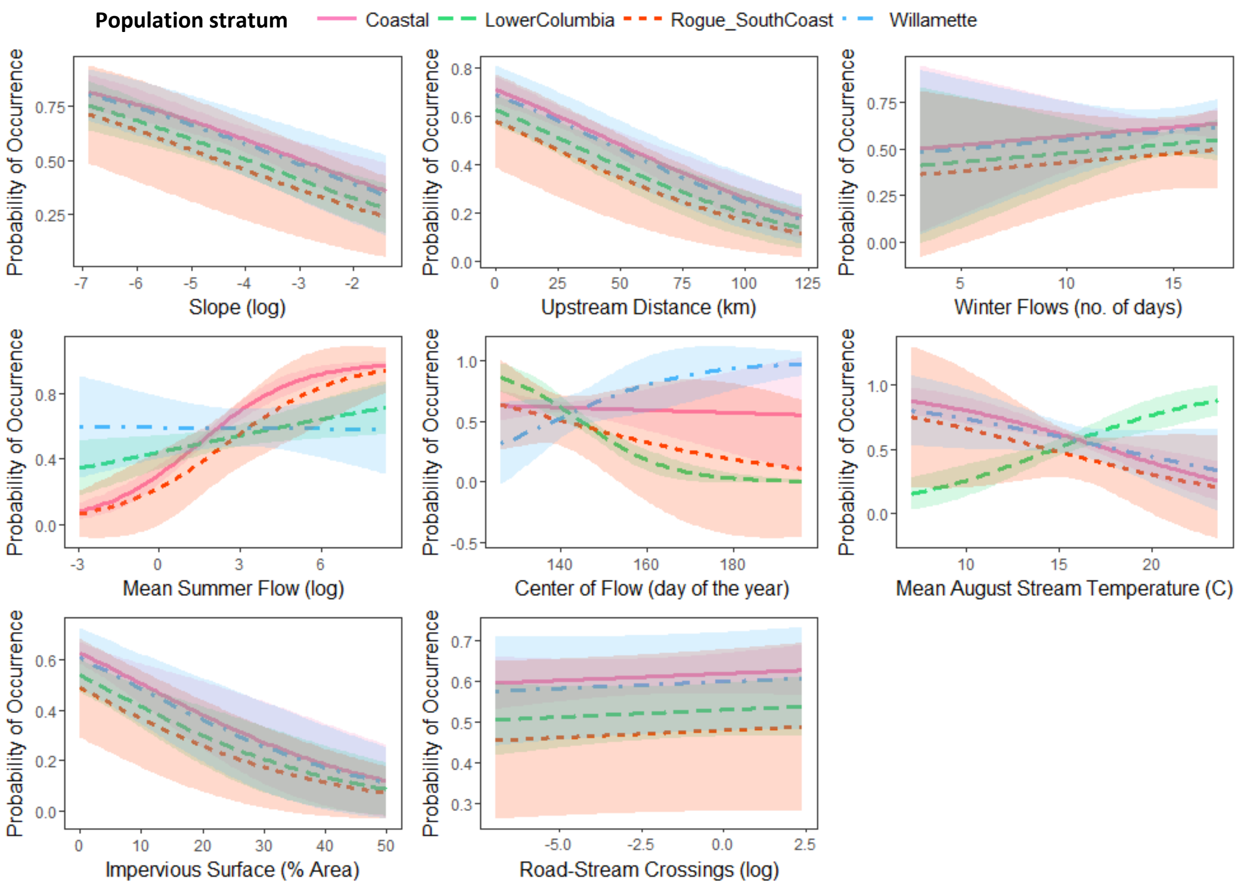

Figure A5.8. Probability curves and confidence intervals around estimates for Pacific Lamprey. Line colors delineate the four different population strata with a semi-transparent boundary denoting the upper 95th confidence interval.

Table A5.7. Simple slopes for interaction terms in the final SDM for Pacific Lamprey. PS represents the population strata: Lower Columbia, Coastal, Willamette, and Rogue/South Coast.

Parameter	Estimate	Std. Error	p-value
PS*Mean Summer Flow (log)			
PS/Coastal*Mean Summer Flow (log)	0.551	0.090	0.000
PS/Lower Columbia*Mean Summer Flow (log)	0.138	0.078	0.077
PS/Rogue South Coast*Mean Summer Flow (log)	0.489	0.262	0.062
PS/Willamette*Mean Summer Flow (log)	-0.005	0.121	0.965
PS *Center of Flow			
PS/Coastal*Center of Flow	-0.005	0.017	0.795
PS/Lower Columbia*Center of Flow	-0.099	0.022	0.000
PS/Rogue South Coast*Center of Flow	-0.038	0.052	0.463
PS/Willamette*Center of Flow	0.065	0.042	0.121
PS*Mean August Temperature			
PS/Coastal*Mean August Temperature	-0.183	0.064	0.004
PS/Lower Columbia*Mean August Temperature	0.237	0.086	0.003
PS/Rogue South Coast*Mean August Temperature	-0.151	0.193	0.436
PS/Willamette*Mean August Temperature	-0.137	0.110	0.252

Table A5.8. Parameter estimates for predictor variables in the final SDM for Pacific Lamprey. PS represents the population strata: Lower Columbia, Coastal, Willamette, and Rogue/South Coast.

Parameter	Estimate (odds ratio)	Std. Error	p-value
Intercept	0.434	2.820	0.878
Slope (log)	-0.353	0.097	0.000
Upstream distance	-0.020	0.004	0.000
PS/Lower Columbia	7.656	3.853	0.047
PS/Rouge/South Coast	2.534	8.216	0.758
PS/Willamette	-9.802	7.462	0.189
Mean August temperature	-0.196	0.066	0.003
Winter flows	0.042	0.096	0.660
Mean summer flow (log)	0.542	0.094	0.000
Center of flow mass	-0.002	0.018	0.934
Percent impervious surface	-0.047	0.017	0.0005
Road-stream crossings	0.029	0.027	0.268
PS/Lower Columbia*mean summer flow (log)	-0.376	0.117	0.001
PS/Rogue/South Coast*mean summer flow (log)	-0.082	0.271	0.762
PS/Willamette*mean summer flow (log)	-0.506	0.149	0.001
PS/Lower Columbia*center of flow	-0.093	0.029	0.001
PS/Rogue/South Coast*center of flow	-0.027	0.055	0.621
PS/Willamette*center of flow	0.063	0.047	0.180
PS/Lower Columbia*mean August temperature	0.409	0.102	0.000
PS/Rogue/South Coast*mean August temperature	0.064	0.203	0.752
PS/Willamette*mean August temperature	0.106	0.131	0.417

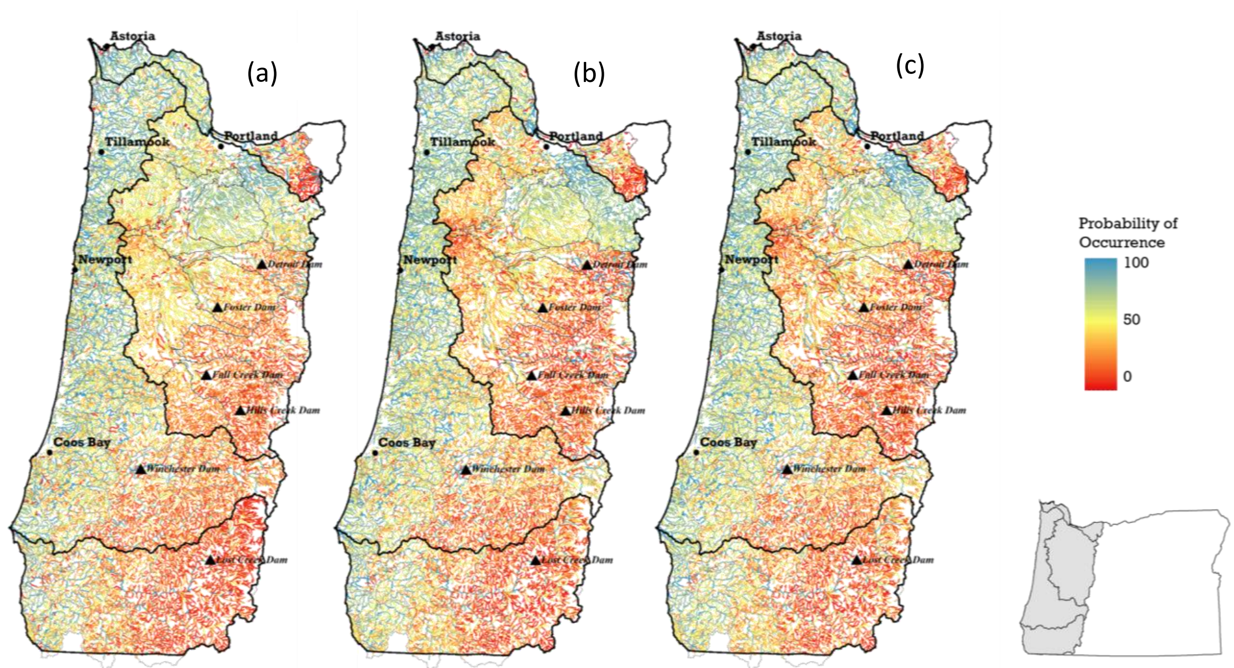

Figure A5.9. Probability of occurrence of Pacific Lamprey across population strata in Western Oregon, including (clockwise, from lower left) the Rogue/South Coast, Coastal, Lower Columbia, and Willamette strata. The probability of occurrence is based on the best distribution model for (**A**) baseline (1993 – 2011), (**B**) based on 2040 projections of stream temperature and stream flow, and (**C**) based on 2080 projections of stream temperature and stream flow. The color ramp represents the probability of occurrence, with red being the lowest and blue the highest. Some streams and watersheds (e.g. part of the Smith River in the Rogue/South Coast stratum, and Hood River in the Lower Columbia stratum) did not have flow and/or temperature data available so occurrence probabilities were not estimated. Oregon subset shows the state boundary with the four PS included in this analysis.

DISCUSSION

The probability of Pacific Lamprey occurrence (distribution) was predicted with SDMs. Although modelling can be a powerful tool in fisheries management, it is limited to the baseline data for stream temperatures and flows, spawning ground surveys, and challenges with realizing suitable vs. available habitat. Because the SDMs modeled suitable (rather than available) habitat for lampreys, these models did not control for the presence of artificial obstructions. Whereas this variable can constrain current distribution of Pacific Lamprey, the inclusion of artificial obstructions would probably not have changed the general relationships among lamprey occurrence and the landscape habitats. Similar habitat conditions are observed above and below artificial obstructions; therefore, the relationships inherent in the data remain. A lack of lamprey presence above artificial obstructions is typical; in most cases, this is a function of the barrier and not the condition of the stream habitat. Finally, artificial obstructions are generally not associated with stream habitats; rather, these obstructions are present on the landscape in association with human values (e.g. road building). However, many artificial obstructions occur throughout the distribution of Pacific Lamprey and these can affect passage (Chelgren and Dunham 2015). Therefore, the influence of artificial obstructions on the probability of occurrence of Pacific Lamprey warrants further investigation.

Pacific Lamprey are distributed widely and they tend to use mainstem streams, which are often relatively low in watersheds. Spawning ground surveys for steelhead conducted by ODFW's OASIS program provided the majority of the information that populated the SDMs (Table A5.1). However, these surveys may be missing large numbers of spawning Pacific Lamprey that could occur below the steelhead survey frame.

Interactions among population strata (PS) and both stream temperature and stream flow variables were observed. The probability of occurrence of Pacific Lamprey increased with increases in summer flows for all PS except the Willamette. In the Willamette, the regulated nature of the stream systems has altered stream flows such that relationships become more difficult to disentangle. A negative relationship was detected between center of stream flow in the Lower Columbia and occurrence of Pacific Lamprey. This indicates that when stream flows are higher later in the year, Pacific Lamprey are more likely to occur in this PS. Whereas the coastal basins of this PS yield hydrological patterns similar to the Coastal PS, the Sandy Basin is notably different and may be contributing to the results, given the large number of snow-melt dominated stream flows in the basin.

Finally, a relationship was detected among stream temperature and occurrence of Pacific Lamprey in the Coastal and Lower Columbia PS. In the Coastal PS, a negative relationship between August mean stream temperature and occurrence of Pacific Lamprey was detected. This indicates that as mean August stream temperatures increase, the mean probability of lamprey occurrence decreases. In the Lower Columbia, a positive relationship between mean August temperatures and the probability of occurrence of Pacific Lamprey was detected. As noted above, the watersheds draining the Cascade Range are distinct from the coastal basins and these relationships may influence the results.

The majority of the occurrence data for Pacific Lamprey used in this analysis was collected in the spring and early summer. However, the stream flow and temperature data reflected August conditions. Whereas May temperatures in a particular stream reach are correlated to August temperatures, a temporal mismatch exists between these datasets. A relationship exists among stream flow and stream temperature and the occurrence of Pacific Lamprey. However, further exploration is needed to ascertain the specific relationships among hydrological stream conditions and occurrence of Pacific Lamprey.

Indirect challenges to lampreys resulting from climate change include deterioration of habitat conditions (water quality and quantity, physical habitat, and habitat access) at increasingly rapid rates over the course of the 21st century. Degraded and fragmented river habitats with artificial obstructions will be most affected by climate change (Williams et al. 2015a, b). Direct challenges to lampreys from climate change include physiological stress, delayed mortality, misalignment of environmental cues with species adaptations, and instant mortality through trauma or predation (Appendix 3; Table A9.1). These challenges to lampreys may result in changes to their behavior, distribution, and abundance, potentially culminating in extirpation of population(s) from particular watersheds and genetic adaptation.

The exacerbation of limiting factors by climate change will affect all strata, although the effects will vary by stratum. Population strata in interior Oregon (Mid Columbia, Lower Snake and Upper Snake), will be highly impacted by climate change for four reasons. First, these strata are the farthest from the ocean. Second, anadromous lampreys in these strata are already significantly limited by numerous artificial obstructions on the mainstem Columbia River (Table 3.4; Sharma et al. 2016). Third, these strata have river flows dominated by snowmelt, which will decrease with decreased snowpack. Fourth, these interior strata are predicted to experience significant increases in water temperatures (Wade et al. 2013; Mote et al. 2014; Williams et al. 2015a; Sharma et al. 2016). It is surmised that the aforementioned alterations to water quantity (decreased flows) and quality (increased temperature) will render re-establishment of Pacific Lamprey in the Upper Snake stratum challenging. In the low elevation areas of the Rogue/South Coast and Willamette strata, high water temperatures that will stress steelhead populations[25] are predicted (Wade et al. 2013). These assessments by Wade et al. (2013) generally coincide with ODFW's assessments (Figures A5.2 and A5.9; Table 5.3). These project the Rogue/South Coast and Willamette strata and portions of the Coastal and Lower Columbia strata to exhibit more areas with significantly warmer water temperatures in 2040 and 2080 (Figure A5.2) and less probability of occurrence of Pacific Lamprey (Figure A5.9; Table 5.3). Therefore Pacific lamprey may experience thermal stress in the low-elevation areas of the Rogue/South Coast and Willamette strata, and portions of the Coastal and Lower Columbia strata. Within the Coastal stratum, the Umpqua Basin was the most vulnerable (ranked as "Extremely Vulnerable") to climate change of all of 15 river basins examined for vulnerability to climate change with respect to Pacific Lamprey in Washington, Oregon, and California (Schaller et al. 2017). Schaller et al. (2017) identified the limiting factors in the Umpqua to be dewatering and flow management (i.e., water quantity per Table 5.2), and stream and floodplain degradation (i.e., physical habitat per Table 5.2).

Key conclusions for SDM results are presented in Chapters 3 and 5. Additional conclusions are as follows:

- the SDM results likely reflects habitat conditions of larval lamprey (assuming successful reproduction at the sites where redds were identified)
- the SDMs were limited by the range of baseline data (1993 – 2011) for stream temperatures and flows that populated the models. Historical (i.e., pre-1993) or future (post 2011) deviations in stream temperatures and flows beyond baseline

[25] *These high water temperatures will likely stress lamprey populations as well. Like lampreys, steelhead are springtime spawners and they co-occur with them throughout Oregon.*

conditions may render results in lamprey occurrence that do not concur with model predictions

- the probability of occurrence of Pacific Lamprey decreased with slope, upstream distance, and the percent of impervious surface (Figure A5.8)
- the probability of occurrence of Pacific Lamprey increased with winter flows (Figure A5.8), which may be reflective of flashy streams. Pacific Lamprey have been categorized as "periodic" life history strategists that use habitats that vary significantly in time and space (Clemens et al. 2013), which may equate to flashy streams. In addition, radio-tagged adult Pacific Lamprey have been recorded migrating further upstream in a year with greater stream flows vs. in a previous year with lower flows (Clemens et al. 2017b)
- the probability of occurrence of Pacific Lamprey increased in association with increasing mean stream temperature during August in the Lower Columbia stratum, but decreased in the other strata (Figure A5.8)
- the probability of occurrence of Pacific Lamprey in relation to flow metrics varied by stratum (Figure A5.8)
- a lack of distribution data precluded development of SDMs for Pacific Lamprey in Eastern Oregon.

Appendix 6. Supporting information for assessing adult abundance trends

This appendix presents details on the Methods, Results, and Conclusions of various ways of assessing abundance indices over time (i.e., trends) of adult Pacific Lamprey. The main conclusions are presented in Chapters 3.

METHODS

Adult abundance data for Pacific Lamprey exists for the Rogue/South Coast, Coastal, Lower Columbia, and Willamette population strata (Tables A6.1 – A6.2). The methods for assessing abundance for adult Pacific Lamprey include adult counts at dams, redd counts from spawning ground surveys, and mark/recapture abundance estimates. Trends in adult abundance were ascertained using simple statistical correlations and professional opinion of graphical trends.

Adult abundance data should be considered relative abundance indices and not population estimates because population structure of Pacific Lamprey is not well-defined and detection efficiencies from dam counts and redd surveys are unknown. Abundance indices from adult counts at dams and from spawning ground surveys were compared with statistics (Pearson Product moment correlations). Each correlation results in a value that is a proportion (i.e., < 1.00). Relatively strong and statistically significant correlations were considered to be ≥ 0.50, with probabilities ≤ 0.10. Direct correlations are those where each factor rises in association with another factor, and are signified by positive correlation values. By contrast, indirect correlations are those where one factor decreases as another rises, and are signified by negative correlation values. Mark/recapture abundance estimates for adult Pacific Lamprey have large error estimates; therefore, these were not used in statistical comparisons.

Abundance indices from adult counts at dams

Dam counts present three main challenges to analyses, and assessment of abundance:

- dam counts are raw numbers and do not account for fish passage efficiency
- strategies for counting adult lamprey vary by each dam, rendering comparisons among dams challenging
- dams typically are artificial obstructions to lamprey migrations, and as such are identified as key limiting factors (Chapter 5). Dams may therefore constrain passage behavior and localized population characteristics — and thereby the actual counts — to unknown extents.

Nevertheless dam counts present the sole source of historic numbers that can be used to observe trends.

Table A6.1. Inventory of data for adult abundance of Pacific Lamprey, from the Oregon Department of Fish and Wildlife.

Research project	Data source	Basin	Focal species	Population stratum	Years	Notes
Gold Ray Dam	Adult fish counts [a, b]	Upper Rogue	Various salmonid species	Rogue/South Coast	1993 – 2009	
Winchester Dam	Adult fish counts [a, c]	North Umpqua	Various salmonid species	Coastal	1965 – 2017	
OASIS [d]	Randomized spawning ground surveys	Various	Steelhead	Coastal Lower Columbia	2007 – 2017	Peak redd counts per mile
Smith River research	ODFW Fish Research	Smith River	Pacific Lamprey	Coastal	2006, 2009	Starcevich et al. (2014)
Leaburg Dam	Adult fish counts [a, e]	McKenzie	Various salmonid species	Willamette	1970 – 2017	
Lower and Upper Bennett Dam	Adult fish counts [a, f]	North Santiam	Various salmonid species	Willamette	2011 – 2017	
Willamette Salmonid RME	Randomized spawning ground surveys; same sites in consecutive years	South Santiam	Steelhead	Willamette	2016 – 2017	Total number of unique redds

[a] Ladder counts do not account for passage efficiency, including lamprey that may bypass the counter. Strategies for counting adult lamprey varied by each dam site.

[b] Video recordings.

[c] Day time window counts of adult Pacific Lamprey in the fish ladder of Winchester Dam, 1965 – 2016, plus counts of lamprey ascending the lamprey ramp (2013 – 2017), with subsampling occurring in the ladder during May 2015 – present (McCormick et al. 2015). During 1965 –1991, ladder counts occurred only during the day. During 1992 – present, camera recordings at the window monitored lamprey counts 24 hours per day (McCormick et al. 2015). Lamprey counts tend to be too sporadic to subsample, and so the adult lamprey counts in the fish ladder represent raw numbers with no extrapolation.

[d] Oregon Adult Salmonid Inventory and Sampling (OASIS) project.

[e] Prior to 1990, various methods of counting and variable data recording protocols were used, including Super 8 filming, trapping, and other methods. Video recordings began in 1993. During 2002 – present, video recordings occurred 7 days a week, 24 hours a day. Prior to 2004, the counting station was on the left ladder bank only. During 2004 – present, counting stations are present on both the left and right bank ladders.

[f] Counts of adult Pacific lamprey were recorded by video cameras 24 hours per day at Upper Bennett Dam and Lower Bennett Dam throughout all years. Counting at Upper Bennett Dam occurs throughout each year, whereas counting at Lower Bennett Dam occurs from April through mid-December. Lamprey were not counted during 2011 and 2015 at Lower Bennett Dam.

Table A6.2. Inventory of data for adult abundance of Pacific Lamprey from projects outside the Oregon Department of Fish and Wildlife. CTWSRO = Confederated Tribes of Warm Springs Reservation of Oregon. USACE = U.S. Army Corps of Engineers.

Research project / data source	Basin	Focal species	Population stratum	Years	Locations where data collected
Academic research	North Umpqua	Pacific Lamprey	Coastal	2009 – 2010	Winchester Dam [a]
USACE adult daytime window counts	Columbia	Multiple	mainstem Columbia [b]	1946 – 1969; 1999 – 2017	Bonneville Dam [c]
USACE adult daytime window counts	Columbia	Multiple	mainstem Columbia [b]	1957 – 1969; 1999 – 2017	The Dalles [c]
USACE adult daytime window counts	Columbia	Multiple	mainstem Columbia [b]	1968 – 1969; 1999 – 2017	John Day [c]
USACE adult daytime window counts	Columbia	Multiple	mainstem Columbia [b]	1954 – 1969; 1999 – 2017	McNary [c]
USACE adult daytime window counts	Snake	Multiple	mainstem Snake [b]	1999 – 2017	Lower Granite [c]
CTWSRO mark/recapture abundance estimates; harvest estimates	Willamette	Pacific Lamprey	Lower Columbia, Willamette	2010 – 18	Willamette Falls [d]
CTWSRO mark/recapture abundance estimates; harvest estimates	Fifteenmile Creek	Pacific Lamprey	Mid Columbia	2011 – 17	Cushing Falls [d, e]
CTWSRO mark/recapture abundance estimates; harvest estimates	Deschutes	Pacific Lamprey	Mid Columbia	2004 – 17	Sherars Falls [d, e]

[a] Lampman (2011)

[b] Not a population stratum

[c] Daytime window count data available at FPC (2018). Fish ladder counts are raw numbers and do not account for fish passage efficiency.

[d] Baker (2016); Baker and McVay (2015, 2016, 2017, 2018, 2019)

[e] Baker et al. (2015); Johnsen and Baker (2017 and 2018)

Abundance indices from spawning ground surveys

Spawning ground surveys occurred as part of monitoring for spawning winter steelhead populations in Western Oregon, including tributaries of the Coastal, Lower Columbia, and Willamette strata. These surveys were conducted by OASIS and the Willamette Salmonid RME (Table A6.1)[26]. Field crews recorded data on lamprey redds. The peak number of redds per mile, per site was averaged by year and basin, and then divided by the number of survey miles. Next, the average of the peak redds per mile was calculated. Surveys sites (each approximately one mile long) were selected using a spatially-balanced, random design from within the steelhead spawning distribution (survey frame). Comprehensive monitoring began in

[26] *Data from the Willamette strata above Willamette Falls differed from that of the Willamette strata below Willamette Falls and the Coastal and Lower Columbia strata in three ways. One, surveys above Willamette Falls tallied the total number of unique lamprey redds per survey mile, whereas the other surveys used the average peak number of lamprey redds per survey mile. Two, surveys above Willamette Falls calculated abundance by the total number of miles within the steelhead survey frame, whereas surveys elsewhere calculated abundance by the total number of miles within the U.S. Fish and Wildlife Service's survey frame for Pacific Lamprey, which provides a consistently lower estimate of the abundance index for Pacific Lamprey in comparison with the steelhead survey frame. Three, surveys above Willamette Falls surveyed the same sites in the second year that were identified by random design in the first year. Surveys elsewhere use randomized survey design to identify survey sites every year.*

2003 along the Oregon Coast and in 2012 in the Lower Columbia River (Astoria to Hood River). Records of lamprey data were standardized in 2007, as counts of all lamprey and redds observed on each survey visit. Survey efforts varied substantially across years and between Distinct Population Units (DPS) of steelhead. Since 2009 the number of survey sites ranged from 120 – 180 in the Oregon Coast DPS, and 100 to 150 in the Lower Columbia River. Given the data standardization in 2007, only data from 2007 onward were used. An average of eight sites were surveyed per basin. Twenty individual river basins, from the Necanicum River in the north to the South Umpqua River Basin in the south, were surveyed in the Coastal stratum, plus assorted, small coastal "dependent" basins. The data from these basins were rolled up into one overall abundance index, per year, for the Coastal stratum. Similarly, five individual river basins draining into the Lower Columbia River were surveyed. Unlike the Coastal stratum, in which all basins were sampled each year, not all basins in the Lower Columbia stratum were sampled each year. In some years only one basin was sampled. The Clatskanie, Scappoose, and Sandy River Basins were all surveyed for five of the eight years of monitoring so the data from these was rolled up into one overall abundance index, per year, for the Lower Columbia stratum. In the Willamette stratum only the Clackamas and South Santiam River Basins were sampled. The Clackamas Basin was sampled in all seven years that monitoring occurred and represents the Willamette stratum. The South Santiam Basin was only sampled in 2016 and 2017 and was therefore not included in the rolled up overall, abundance index for the Willamette stratum.

To extrapolate peak redd counts of Pacific Lamprey across distance, and to account for the fact that this species constructs redds that are not used (see Whitlock et al. 2017), an abundance index was created. The abundance index for adult Pacific Lamprey was calculated as follows:

(Average peak lamprey redds per mile) X (Survey frame miles) X (Lamprey per redd)

Where "Lamprey per redd" is data gleaned from the scientific, peer-reviewed literature for Pacific Lamprey. For "Lamprey per redd", the mean, minimum, and maximum numbers were used. For mean lamprey per redd, Whitlock et al. (2017; 0.48 lamprey per redd) was used. This number is quite similar to the 0.462 lamprey per redd estimate from Farlinger and Beamish (1984) for Pacific Lamprey in British Columbia. For minimum lamprey per redd, Brumo et al. (2009; 0.125 lamprey per redd) was used. For maximum lamprey per redd, Whitlock et al. (2009; 0.88 upper 95% confidence interval) was used. This approach assumes that the numbers of Pacific Lamprey per redd generated by Whitlock et al. (2009) in the Luckiamute River, Oregon) and Brumo et al. (2009) in the Coquille River, Oregon are similar across years and basins in Oregon. These assumptions should be challenged and tested and replaced with better information if and when it becomes available.

For spatial, seasonal timing and data reasons, the aforementioned abundance index for Pacific Lamprey is a conservative estimate of the number of lamprey in each stratum:

- the surveys are focused on steelhead, and therefore may be missing lamprey outside of the spatial and seasonal extent of steelhead spawning, resulting in an underestimate of the population of spawning lamprey in the particular survey
- the steelhead survey season runs February – May, yet Pacific Lamprey spawning extends into June and occasionally July (Brumo et al. 2009). Lamprey spawn activity after May is not documented in random OASIS spawning ground surveys, which can result in an underestimate of the entire population (Jacobsen et al. 2014, 2015; Brown et al. 2017)
- with the exception of surveys in the South Santiam Basin (Willamette stratum[7]), the metric of peak lamprey redds per mile is the maximum number of redds observed on a single survey date, not the total number of redds created over the entire spawning

season. The ratio of total redds to peak count of redds is unknown. Since the total redds is the peak count or higher, using peak lamprey redds per mile likely results in an underestimate of spawning Pacific Lamprey.

Abundance estimates from mark and recaptures

Mark/recapture abundance estimates were conducted by ODFW (Starcevich et al. 2014) and the Confederated Tribes of the Warm Springs Reservation of Oregon (Baker et al. 2015, 2016; Baker and McVay 2015, 2016, 2017, and 2018; Johnsen and Baker 2017 and 2018) following protocols for tagging and recapturing adult lamprey.

Mark/recapture abundance estimates of adult Pacific Lamprey are challenging for four reasons:

- the “population at-large” is not well defined or known (Appendix 3). For example, in earlier studies, approximately 50 – 81% of all tagged adult Pacific Lamprey at Willamette Falls fall back downstream, destined for elsewhere (Mesa et al. 2010; Baker and McVay 2015, 2016, 2017, 2018; Baker 2016)
- the time series for these studies, in comparison with dam count data, is fairly short (i.e., two to eight years)
- the geographical coverage for Oregon is limited to three strata, the Coastal, Lower Columbia and the Mid Columbia
- the large error ranges of some of these estimates or limited time periods (i.e., two years) preclude using them in statistical comparisons.

RESULTS AND DISCUSSION

Historical abundance

The following presents valuable information from Euro-American settlers and Native American tribes on the high abundance of adult Pacific Lamprey in Oregon during the late 1800s and early 1900s, followed by a rapid decline during the 1950s and 1960s, and then again in the 1980s. Taken together this information captures a general description of historic abundance for adult Pacific Lamprey. This quote is an example of the abundance of Pacific Lamprey at Willamette Falls (Willamette stratum) in the late 1800s: “*At the falls of the Willamette River, near Oregon City, Oreg., on June 23, the rocks at the particular part of the falls where salmon ascend were at times completely covered with lampreys. In places where the force of the current was least they were several layers deep, and at a short distance the rocks appeared to be covered with a profuse growth of kelp or other water plants*” (McDonald 1894). This abundance of Pacific Lamprey has not been observed since at least the 1940s and 1950s, when harvest at Willamette Falls was at its most intense, yielding numbers that far exceeded the dam counts of lamprey at Bonneville Dam (Mattson 1949; Kostow 2002; Figures A6.3 and A8.1). Significant declines in the abundance of Pacific Lamprey in streams within reservations was noticed by various tribes during the 1950s and 1960s (Coastal and Mid Columbia strata; Close et al. 2004; Sheoships 2014), and by the 1970s tribal members in the interior Columbia River Basin (Mid Columbia stratum) noticed significant declines in the numbers of adult Pacific Lamprey (CRITFC 2011). More recently, (1981 – 1991), within the Siletz River Basin (Coastal stratum), tribal members noticed significant declines in Pacific Lamprey (Downey et al. 1996).

Abundance indices from adult counts at dams

Counts of adult Pacific Lamprey at dams exist for Gold Ray Dam on the Rogue River (Rogue/South Coast stratum; Figure A6.1), Winchester Dam on the North Umpqua River (Coastal stratum; Figure A6.2), the mainstem Columbia and Snake rivers (Figure 3.6), Leaburg Dam on the McKenzie River (Willamette stratum; Figure A6.4A), and the Lower and Upper Bennett dams on the North Santiam River (Willamette stratum; Figure A6.4B).

Along the Oregon coast and into the Columbia River, a significant decrease in dam counts of adult Pacific Lamprey has occurred since the late 1950s and early 1960s (Figures A6.2 – A6.3). The relative abundance of adult Pacific Lamprey declined over time at Gold Ray Dam in the Upper Rogue River (Rogue/South Coast stratum) from nearly 2,500 down to < 50 per year (Figure 3.4; data time series: 1993 – 2009); and at Winchester Dam on the North Umpqua River (Coastal stratum) from about 50,000 down to < 50 per year (Figure A6.2; 1965 – 2017; Table A6.3). Numbers of adult Pacific Lamprey at Bonneville Dam decreased from approximately 400,000 individuals in 1969 during peak abundance, down to < 20,000 individuals in 2000 (Figure A6.3). Despite this 20 fold decrease in adult Pacific Lamprey counted at Bonneville Dam, the correlation between dam counts and years was fairly weak (Table A6.3). This may be due to the non-linear nature of the periodic abundance cycles (Figure A6.3). Abundance indices from adult counts at dams on the mainstem Columbia River drops steeply as one proceeds upstream from Bonneville Dam and into the Snake River, where the average number of adult Pacific Lamprey passing Snake River Dams viewing windows each year is only 80 fish (range: 12 – 346; Figure A6.3). Correlations of abundance indices from 1999 – 2009 indicate an apparent intensification of the decline in numbers of adult Pacific Lamprey at Gold Ray dam (Figure A6.1; Table A6.3), and by contrast, during 1999 – 2017, a strong increase in numbers at Winchester Dam (Figure A6.2; Table A6.3). However, the increase in adult Pacific Lamprey at Winchester Dam is still a small fraction of the peak abundance that occurred in 1966 (Figure A6.2).

Table A6.3. Correlation coefficients for the number of lamprey counted/estimated on a particular project. Correlations ≥ 0.50 with probabilities ≤ 0.10 are considered to be both strong and statistically significant (indicated in **bold**). Weak, but otherwise statistically significant correlations are indicated in *italics*. Negative correlations indicate decreases in adult Pacific Lamprey abundance indices over time, whereas positive correlations indicate an increase in adult Pacific Lamprey abundance indices over time. SGS = spawning ground surveys; RSC = Rogue/South Coast; CST = Coastal; LC = Lower Columbia, and WI = Willamette.

Project	Population Stratum	Data	Year (entire time series)	Year (1999 – present)
Gold Ray Dam	RSC	Dam counts	**-0.51**	**-0.80**
Winchester Dam	CST	Dam counts	**-0.63**	**0.75**
OASIS	CST	SGS	**0.64**	–
OASIS	LC	SGS	*0.32*	–
OASIS	WI	SGS	**0.54**	–
Bennett Dam	WI	Dam counts	0.28	–
Leaburg Dam	WI	Dam counts	*0.32*	0.17
Bonneville Dam	Mainstem Columbia [a]	Dam counts	*-0.35*	-0.12

[a] Not a population stratum.

Three lines of evidence suggest that adult counts at dams are conservative estimates of abundance within watersheds. First, during 1999, 3,608 adult Pacific Lamprey were tallied at Savage Rapids Dam, 19 miles downstream of Gold Ray Dam, which counted only 523 adult Pacific Lamprey, representing a 6.9 fold difference in numbers (Figure A6.1). Both dams have since been breached. Second, mark/recapture estimates during 2009 and 2010 at Winchester Dam revealed a 12.3 – 42.9 fold increase in numbers above the conventional counts made at that location (Table A6.4; Figure A6.2). Third, an eight to 20 fold difference in abundance estimates is apparent between mark/recapture estimates in one tributary to the lower Umpqua Basin vs. higher up in the basin at Winchester Dam, which is often considered as an abundance indicator for the Oregon Coast (Figure A6.2).

Periodic increases in Pacific Lamprey in the mainstem Columbia River appear to have occurred every eight to 13 years during 1948 – 1969 (at which time counts were halted until 1999), and again on an approximate 14 year cycle during 2003 – 2017 (Figure A6.3). Within the Willamette stratum, the most recent increase in lamprey occurred during 2014 (Figure A6.4), and prior to then, periodic increases appear to have occurred approximately every five to 11 years (Figure A6.4A). Taken together, this information suggests potential wider regional forcings on Pacific Lamprey abundance, and a periodic cycling of relative abundance of approximately five to 13 years, depending on the location. Abundance indices from dam counts indicate a significant decrease in adult Pacific Lamprey from historical numbers over several decades (Figures A6.1 – A6.3).

Table A6.4. Comparison of conventional adult Pacific Lamprey counts at Winchester Dam for two years (Figure A6.2), relative to mark/recapture estimates by Lampman (2011; averages with 95% confidence intervals presented in parentheses), and the magnitude of difference between the conventional counts and mark/recapture estimates.

Year	2009	2010
Adult counts	495	83
Average upstream abundance estimate	960 (188 – 4,760)	556 (110 – 2,798)
Average downstream abundance estimate	5,109 (1,015 – 25,727)	3,003 (596 – 15,122)
Total abundance estimate (summed averages)	6,069	3,559
Magnitude difference, total abundance : adult counts	12.3	42.9

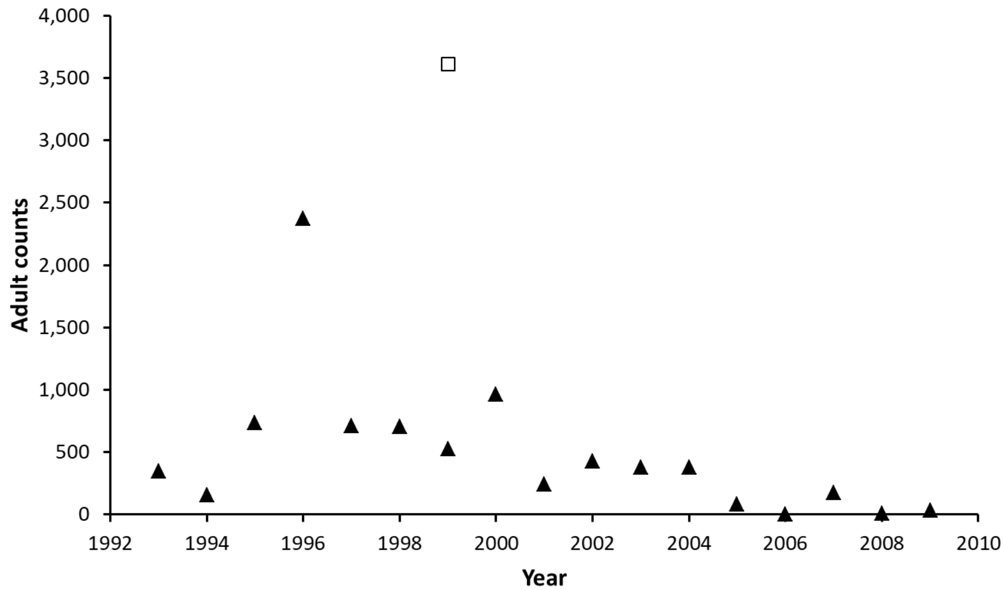

Figure A6.1. Counts of adult Pacific Lamprey at Gold Ray Dam (river mile 126) on the Rogue River (Rogue/South Coast population stratum), 1993 – 2009. Gold Ray Dam was breached in 2010. The single, unfilled square indicates reflects the 3,608 adult Pacific Lamprey that were counted by Oregon Department of Fish and Wildlife staff at Savage Rapids Dam (river mile 107) on the Rogue River, during 1999.

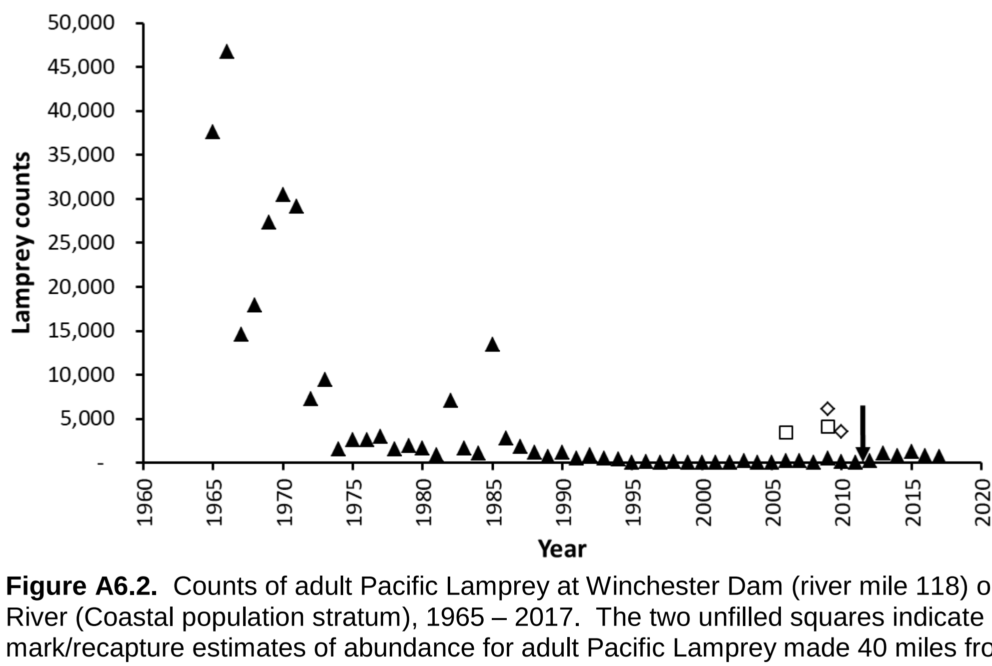

Figure A6.2. Counts of adult Pacific Lamprey at Winchester Dam (river mile 118) on the North Umpqua River (Coastal population stratum), 1965 – 2017. The two unfilled squares indicate the average mark/recapture estimates of abundance for adult Pacific Lamprey made 40 miles from the Pacific Ocean in the Smith River (a tributary to the lower Umpqua River) during 2006 and 2009 (Starcevich et al. 2014). The two unfilled diamonds indicate the mark/recapture estimates of abundance for adult Pacific Lamprey made at Winchester Dam during 2009 and 2010 (Lampman 2011; Table A6.4). The vertical arrow indicates the year (2013) in which the lamprey ramp was first installed to facilitate their passage upstream.

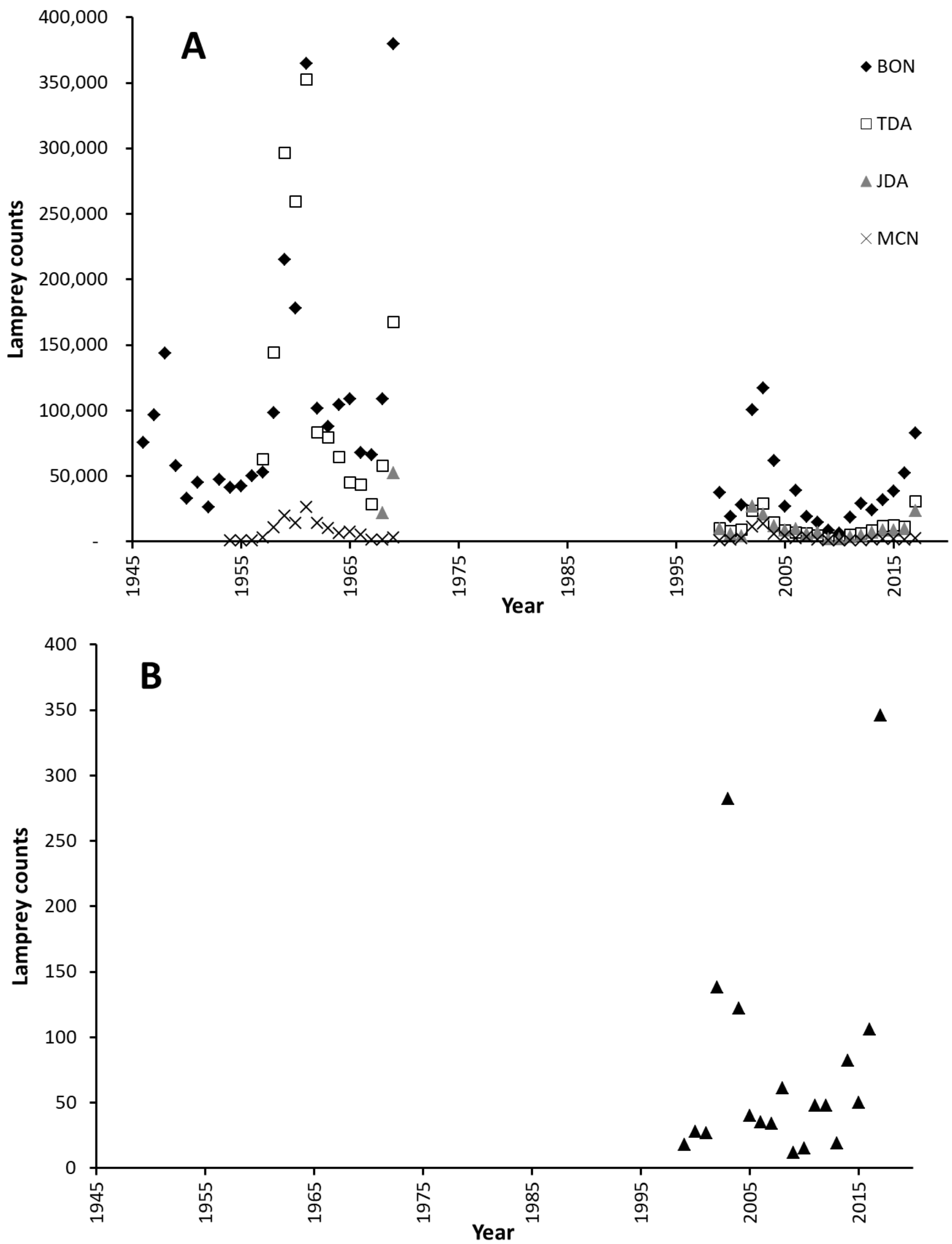

Figure A6.3. A. Counts of adult Pacific Lamprey at four hydropower dams on the mainstem Columbia River: Bonneville Dam ("BON"; river mile 145), The Dalles ("TDA"; river mile 192), John Day ("JDA"; river mile 216), and McNary ("MCN"; river mile 292). Counts occurred prior to 1970 before ending, and then resumed during 1999 – 2017. **B.** Counts of adult Pacific Lamprey at the uppermost dam in the Lower Snake River, Lower Granite Dam (river mile 429)**.** Counts began in 1999. Notice the reduced number of fish compared with panel A. All data from FPC (2018).

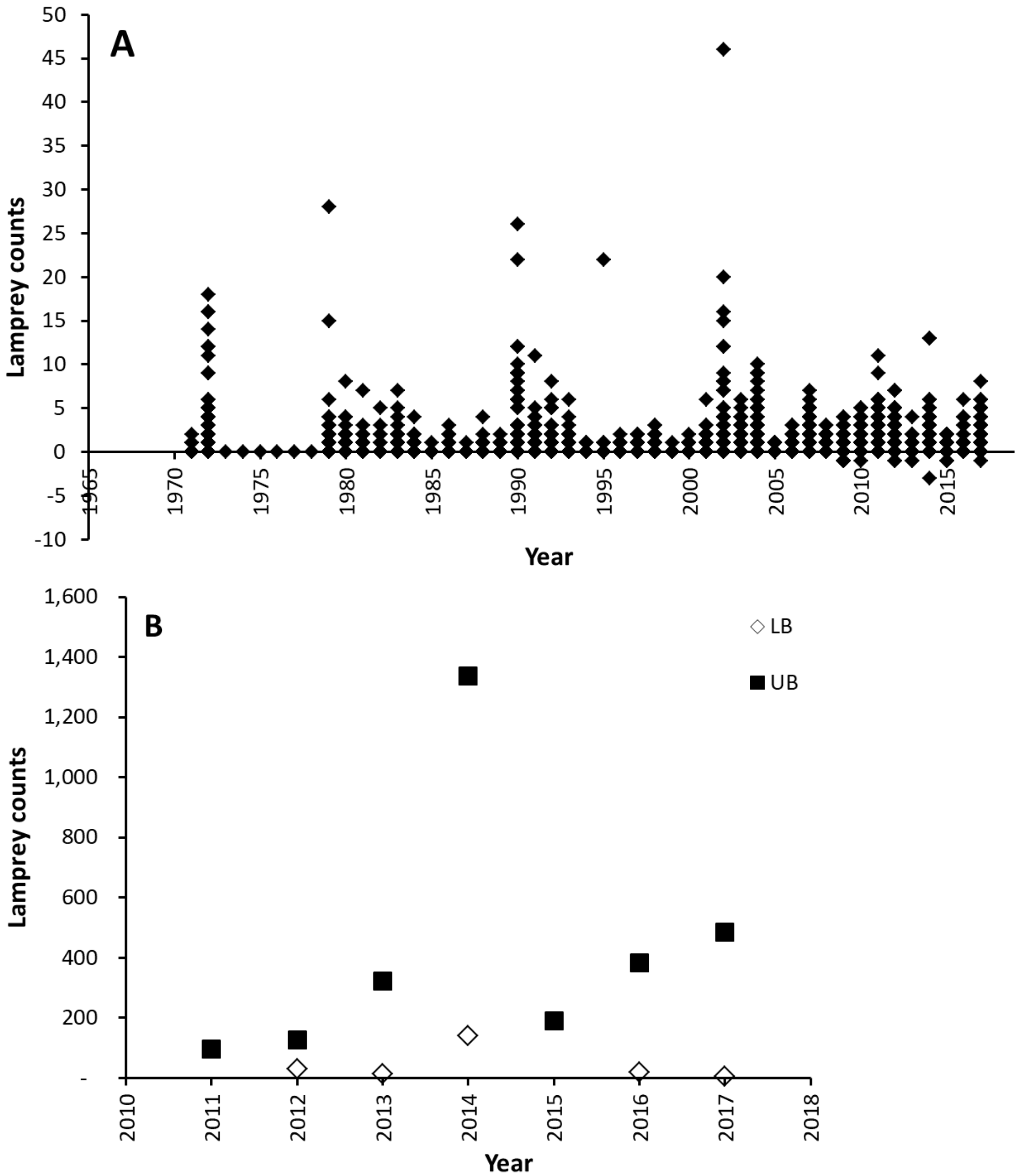

Figure A6.4. Counts of adult Pacific Lamprey at dams in the Willamette population stratum. (**A**) Adult counts at Leaburg Dam (river mile 39) on the McKenzie River. Counts occurred 1970 – 2017. The negative counts after 2010 provide one example of the unknown passage efficiency (more adults may ascend, but avoid the video camera. (**B**) Adult counts at two lowhead dams in the North Santiam River: Lower Bennett Dam ("LB"; river mile 29) and Upper Bennett Dam ("UB"; river mile 32). Counts occurred 2011 – 2017.

Abundance indices from spawning ground surveys

Abundance indices of adult Pacific Lamprey from spawning ground surveys yielded strong, positive correlations over time in the Coastal and Willamette strata, indicating that lamprey numbers have increased over the last seven to 10 years (Table A6.3). The data are provided in Table A6.5. The three strata east of the Cascades (Mid Columbia, Lower Snake, and Upper Snake) lack spawning ground surveys that would enable an estimation of abundance indices.

Table A6.5. Abundance indices from spawning ground surveys conducted by the OASIS project within ODFW.

Population stratum	Basins sampled	Run yr	No. sites in survey frame	Average peak redds/ mi	Sample frame miles	Min	Abundance mean	Max
Coastal	All	2007	169	4.46	2,284.14	1,274	4,893	8,970
Coastal	All	2008	81	5.01	2,284.14	1,430	5,492	10,069
Coastal	All	2009	64	8.05	2,284.14	2,299	8,830	16,188
Coastal	All	2010	97	1.71	2,284.14	487	1,872	3,432
Coastal	All	2011	100	4.15	2,284.14	1,184	4,548	8,338
Coastal	All	2012	105	4.25	2,284.14	1,214	4,661	8,546
Coastal	All	2013	112	8.05	2,284.14	2,299	8,827	16,183
Coastal	All	2014	100	6.28	2,284.14	1,793	6,884	12,621
Coastal	All	2015	115	12.24	2,284.14	3,494	13,416	24,597
Coastal	All	2016	117	16.19	2,284.14	4,623	17,754	32,549
Coastal	All	2017	130	7.75	2,284.14	2,214	8,500	15,584
Lower Columbia	Sandy	2010	28	0.16	100.06	2	8	14
Lower Columbia	Sandy	2011	20	0.00	100.06	0	0	0
Lower Columbia	All	2012	52	4.54	204.94	116	447	819
Lower Columbia	Clatskanie, Scappoose, Sandy	2012	36	4.00	162.23	81	311	571
Lower Columbia	All	2013	87	22.40	204.94	574	2,204	4,040
Lower Columbia	Clatskanie, Scappoose, Sandy	2013	61	11.17	162.23	227	870	1,595
Lower Columbia	Sandy	2014	31	1.90	100.06	24	91	167
Lower Columbia	Clatskanie, Scappoose, Sandy	2015	51	8.78	162.23	178	684	1,253
Lower Columbia	Clatskanie, Scappoose, Sandy	2016	48	23.02	162.23	467	1,793	3,286
Lower Columbia	Clatskanie, Scappoose, Sandy	2017	53	5.20	162.23	105	405	742
Willamette	Clackamas	2011	22	0.32	111.02	4	17	31
Willamette	Clackamas	2012	15	1.41	111.02	20	75	138
Willamette	Clackamas	2013	53	10.25	111.02	142	546	1,001
Willamette	Clackamas	2014	38	30.08	111.02	417	1.603	2,939
Willamette	Clackamas	2015	47	37.40	111.02	519	1,993	3,654
Willamette	Clackamas	2016	24	25.08	111.02	348	1,337	2,450
Willamette	South Santiam	2016	15	34.78	76.96	335	1,285	2,356
Willamette	Clackamas	2017	15	9.35	111.02	130	498	913
Willamette	South Santiam	2017	15	3.37	76.96	32	124	228

The time series for abundance indices from spawning ground surveys is two to 11 years (Table A6.5; Figures A6.5 – A6.7). These data suggest cyclical abundance episodes of six to eight years. Although the time series for both the Lower Columbia and Willamette strata is shorter, all three strata show an apparent increase in abundance index from 2010/2011 through 2015/2016. All three strata also show a decrease in abundance between 2016 and 2017 (Figures A6.5 – A6.6).

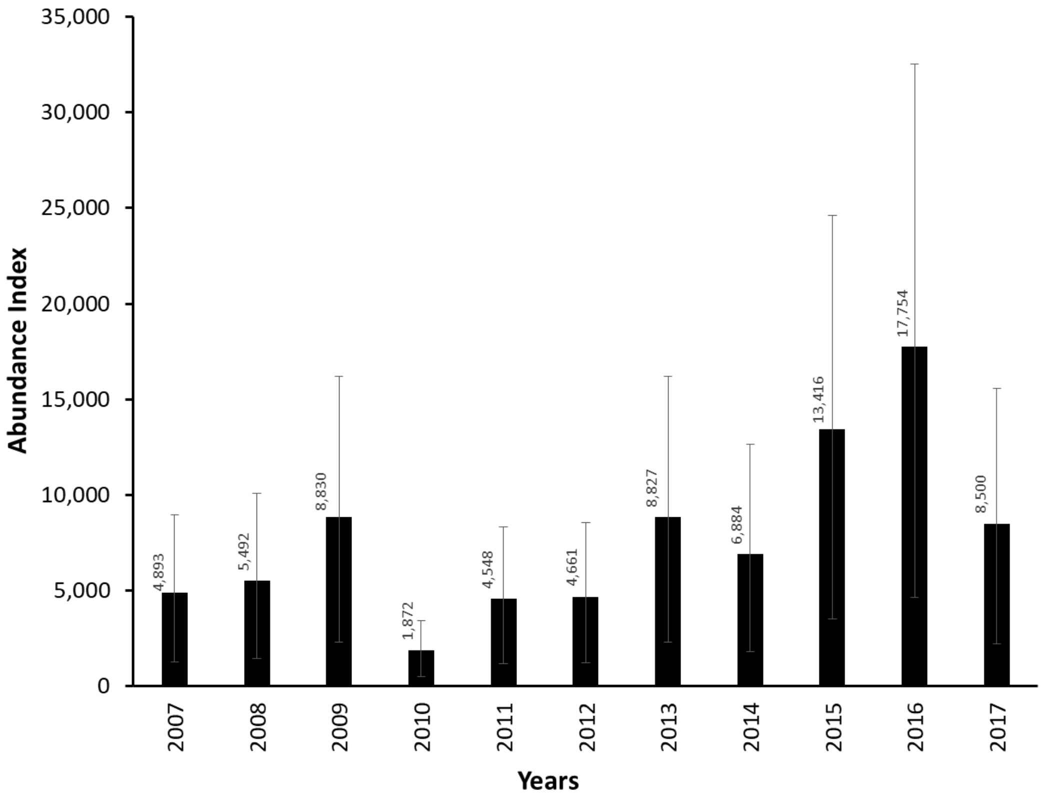

Figure A6.5. Abundance index (numbers shown) for Pacific Lamprey from spawning ground surveys; error bars = minimum and maximum of adult Pacific Lamprey in the Coastal population stratum.

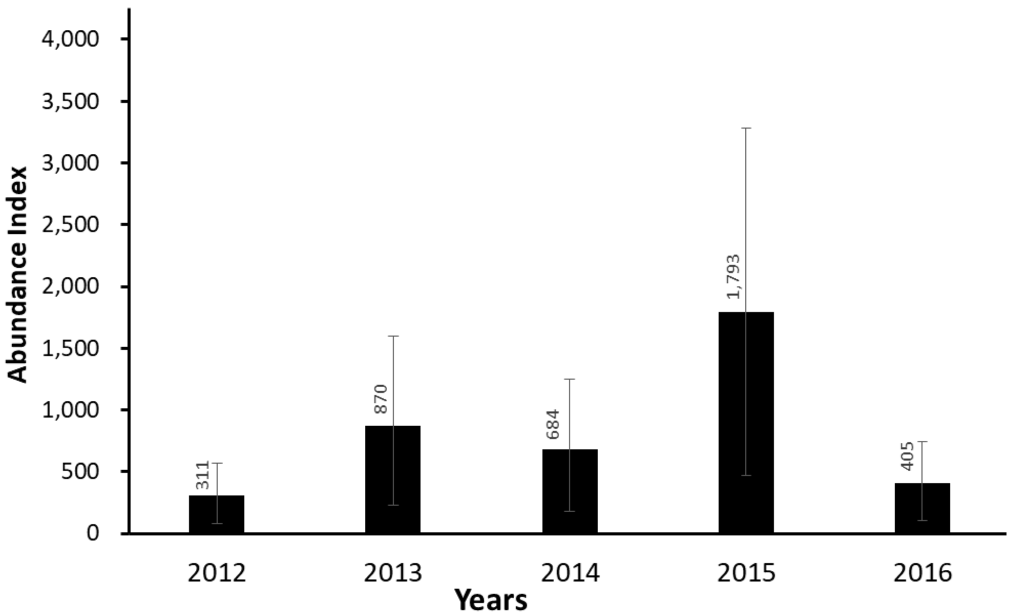

Figure A6.6. Abundance index (numbers shown) for Pacific Lamprey from spawning ground surveys; error bars = minimum and maximum of adult Pacific Lamprey in the Lower Columbia population stratum (Clatskanie, Scappoose, and Sandy Basins only).

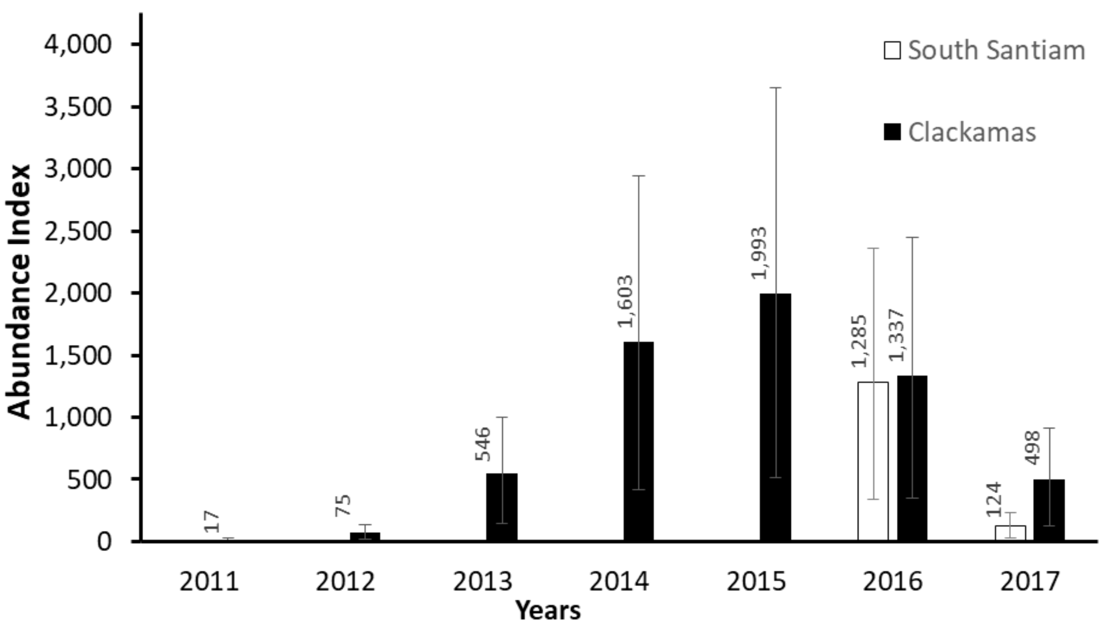

Figure A6.7. Abundance index (numbers shown) for Pacific Lamprey from spawning ground surveys; error bars = minimum and maximum of adult Pacific Lamprey in the Willamette population stratum.

Abundance estimates from mark / recapture estimates

Mark/recapture estimates use marking, subsequent recaptures of marked individuals, and mathematical calculations of the proportion of marked to unmarked lamprey captured to estimate their abundance. These estimates have been done in the following strata: 1) Coastal (Table A6.4 and Starcevich et al. 2014), 2) Willamette (Table A6.6), and 4) Mid Columbia (Table A6.6). Abundance estimates provide actual estimates of the population(s) at-large in part of the Coastal stratum (Figure A6.8), the Lower Columbia stratum, and those escaping above Willamette Falls into the Willamette stratum (Figure A6.9), and at two locations in the Mid Columbia stratum (Figures A6.10 – A6.11).

Information was presented earlier on some of the mark/recapture data for adult Pacific Lamprey at Winchester Dam relative to conventional counts of these fish at that dam (Coastal stratum; Table A6.4, Figure A6.2). Mark/recapture estimates have also been done on adult Pacific Lamprey in the Smith River, a tributary to the lower Umpqua River (Coastal stratum), in which 3,454 adult Pacific Lamprey (3,178 – 3,730 lamprey, 95% confidence interval) were estimated to occur in 2006 and 4,090 (3,804 – 4,376 lamprey) in 2009. These data indicate an eight to 20 fold difference in the number of adult Pacific Lamprey in one tributary low in the Umpqua Basin vs. higher up in the Umpqua Basin at Winchester Dam (Figure A6.2). The mark/recapture estimates at Winchester Dam and in the Smith River indicate the presence of thousands of adult Pacific Lamprey at each of these locations (Figure A6.8) relative to a few hundred counted at Winchester Dam (Figure A6.2).

Like abundance indices from adult counts at dams and spawning ground surveys, abundance estimates indicate a cyclical periodicity of abundance over time, at different locations. Whereas too little information is available to make strong, detailed conclusions with these data, it appears that abundance peaks on a four to 11 year cycle across locations (Figures A6.9 – A6.11). The year 2016 exhibited a relatively large abundance in two separate locations within the Mid Columbia stratum (Figures A6.10 – A6.11), and some asynchronicity in relative abundance may be occurring between the Lower Columbia and Willamette strata (Figure A6.9) relative to the Mid Columbia stratum (Figures A6.10 – A6.11).

Table A6.6. Mark/recapture abundance estimates of adult Pacific Lamprey in three basins, across three population strata. Unless indicated otherwise, the numbers in parentheses are the 95% confidence intervals around the abundance estimate. The data are from the Confederated Tribes of the Warm Springs Reservation of Oregon (Baker et al. 2015; Baker 2016; Baker and McVay 2015, 2016, 2017 and 2018; Johnsen and Baker 2017 and 2018). NA = Estimate not available.

Basin	Population stratum	Years	Locations where data collected	Number Adults
Willamette	Willamette (not passing Willamette Falls)	2010	Willamette Falls	37,345 [a]
		2011		60,564
		2012		131,489
		2013		124,456
		2014		210,527
		2015		136,286
		2016		83,533
		2017		196,729
	Willamette (passing Willamette Falls)	2010	Willamette Falls	27,043 (21,537-33,936) [b]
		2011		46,819 (37,109-59,030) [b]
		2012		11,134 (91,532-135,918)
		2013		51,947 (40,016-60,873)
		2014		127,981 (99,358-159,103)
		2015		32,382 (21,697-47,231)
		2016		32,112 (17,223-57,410)
		2017		80,848 (35,765-159,320)
Fifteenmile Creek	Mid Columbia	2011	Cushing Falls	1,897
		2012		2,498
		2013		1,928
		2014		3,239
		2015		---
		2016		18,483
		2017		NA
Deschutes		2004	Sherars Falls	6,415 (4,725-8,693)
		2005		3,895 (2,847-5,318)
		2006		3,783 (2,595-5,488)
		2007		8,082 (6,352-10,279)
		2008		3,475 (2,384-5,041)
		2009		3,707 (2,699-5,082)
		2010		1,657 (1,201-2,281)
		2011		5,018 (3,805-6,612)
		2012		10,139 (7,874-13,043)

		2013		12,310 (9,889-15,315)
		2014		16,713 (±1,451 SE)
		2015		14,529 (12,498-16,892)
		2016		21,850 [c]
		2017		24,017 (21,336-27,034)

[a] Estimate may be conservative, as the entire run may not have been captured in the study.

[b] Conservative estimate, includes escapement only by fish ladder.

[c] Estimated by simple linear regression for past Sherars Falls escapement numbers vs. Bonneville numbers, plus harvest numbers.

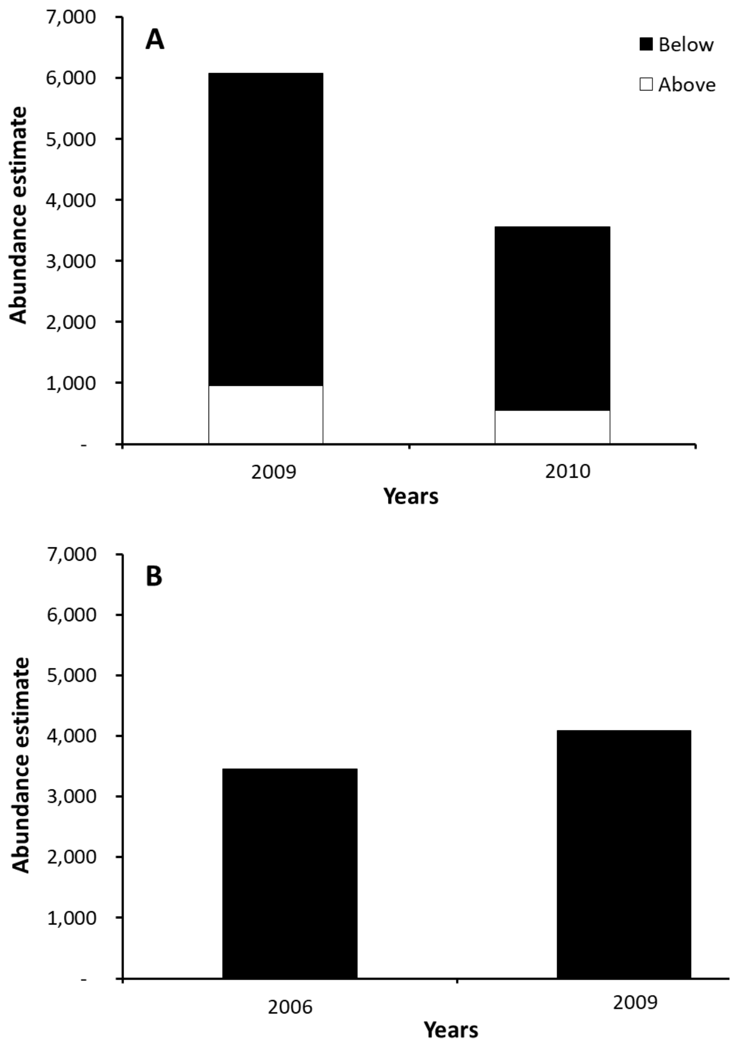

Figure A6.8. Averages of mark/recapture abundance estimates of adult Pacific Lamprey in the Coastal population stratum. (**A**) Winchester Dam (river mile 118) in the North Umpqua River during 2009 – 2010 (Lampman 2011). The 95% confidence intervals for these average abundance estimates are reported in Table A6.4. (**B**) Smith River (a tributary to the lower Umpqua River) during 2006 and 2009 (Starcevich et al. 2014). The 95% confidence intervals for these average abundance estimates are provided in the text.

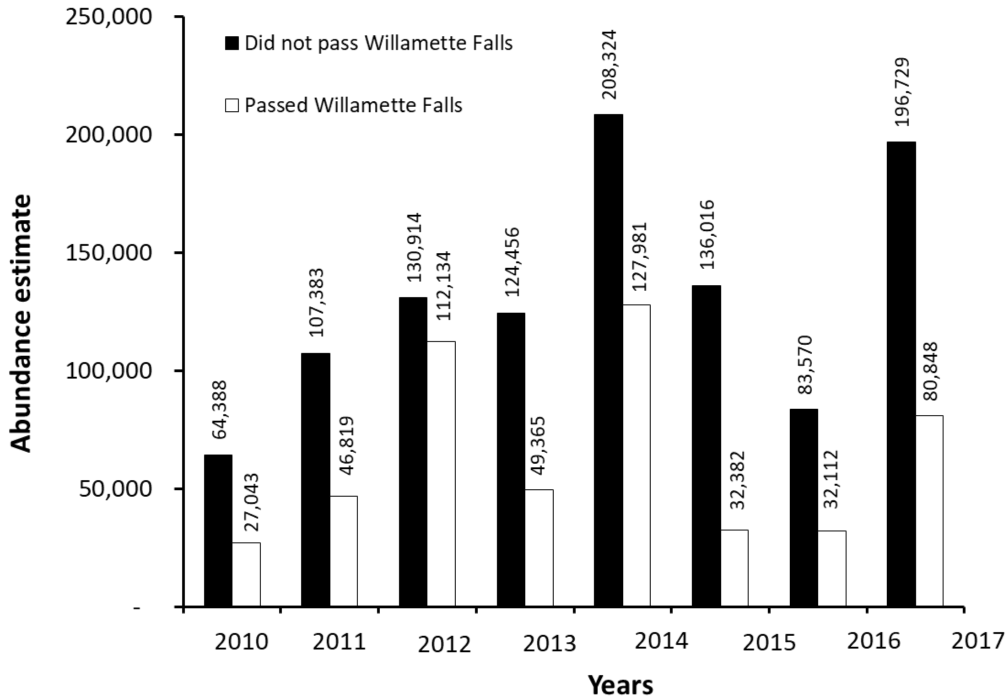

Figure A6.9. Abundance estimates (numbers shown) of adult Pacific Lamprey from mark/recapture studies at Willamette Falls (Willamette population stratum), conducted by Baker and McVay (2015, 2016, 2017 and 2018), and Baker et al. (2016). The dark bars represent the group of lamprey that stayed below Willamette Falls and the clear bars represent the group of lamprey that passed above Willamette Falls.

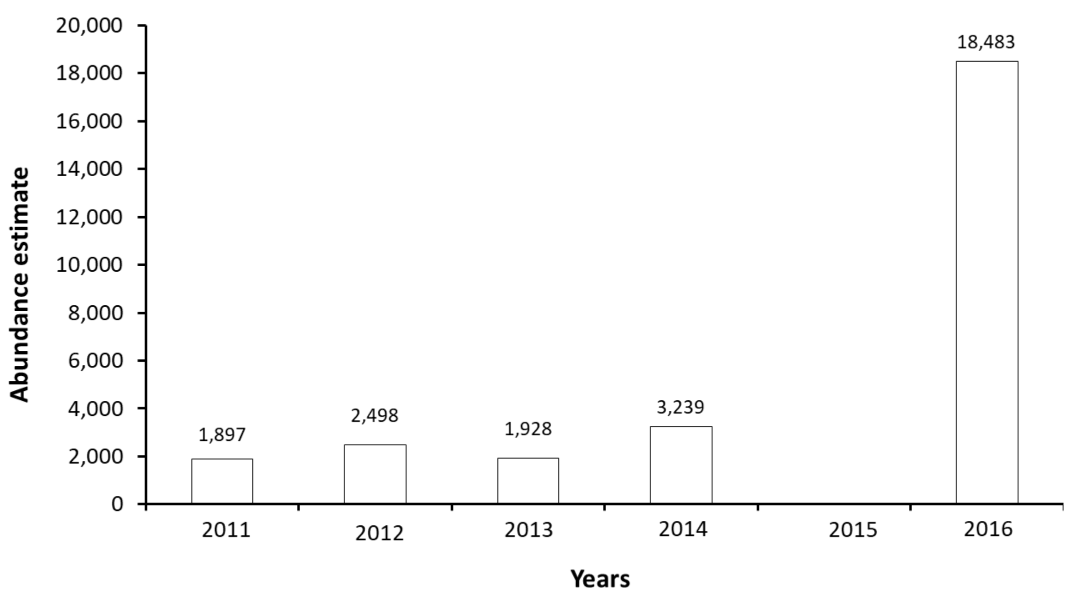

Figure A6.10. Abundance estimates (numbers shown) of adult Pacific Lamprey from mark/recapture studies at Cushing Falls (Fifteenmile Creek; Mid Columbia population stratum), conducted by Baker (2016), and Johnsen and Baker (2017). Data were not available for 2015 or 2017.

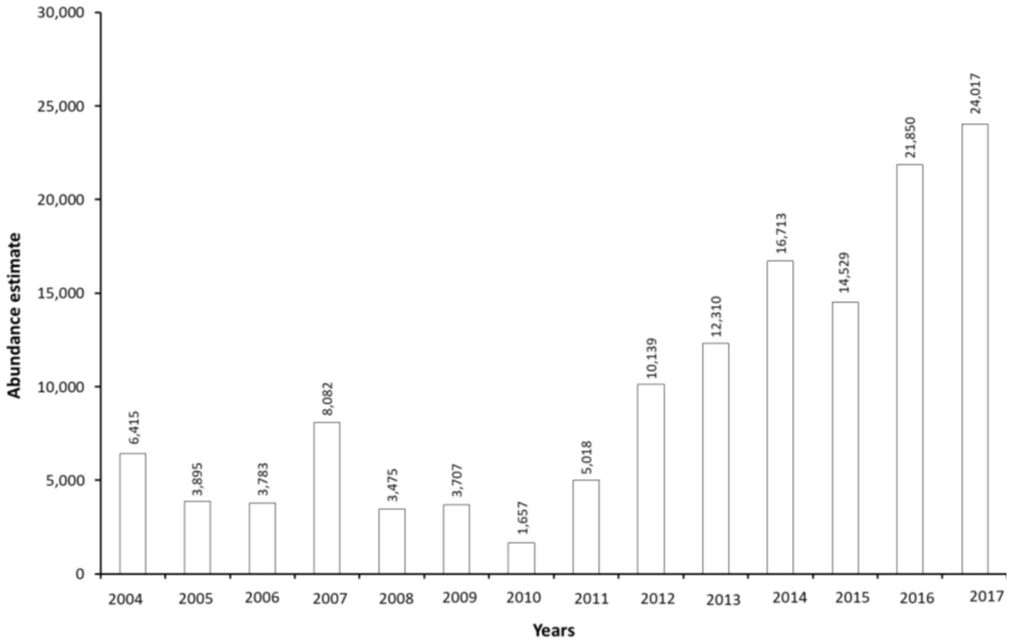

Figure A6.11. Abundance estimates (numbers shown) of adult Pacific Lamprey from mark/recapture studies at Sherars Falls (Deschutes River; Mid Columbia population stratum), conducted by Baker (2016), and Johnsen and Baker (2017 and 2018).

Cross-data comparisons

Analyses and comparisons of the abundance indices from counts of adult Pacific Lamprey at dams, extrapolations from redds during spawning ground surveys, and mark/recapture abundance estimates reveal 10 emergent patterns:

- through counts at Savage Rapids Dam below Gold Ray Dam, and through mark/recapture abundance estimates in the Umpqua Basin, it is apparent that in at least some circumstances, dam counts underestimate the relative abundance of adult Pacific Lamprey
- none of the three dam counts correlate very well with each other (Table A6.7)
- a strong, positive correlation exists between Bonneville Dam counts and spawning ground surveys within the Coastal stratum (Table A6.7)
- a strong, positive correlation exists between Winchester Dam counts and spawning ground surveys within both the Coastal and Willamette strata (Table A6.7)
- a strong, positive correlation exists between spawning ground surveys within the Coastal stratum and those in the Lower Columbia and Willamette strata (Table A6.7)
- the recent increase in adults at Bonneville Dam during 2017 (Figure A6.3) appears to correspond with an increase in abundance estimate of adult Pacific Lamprey at two locations, Cushing Falls (Fifteenmile Creek) and Sherars Falls (Deschutes River) in the Mid Columbia stratum (Figures A6.10 – A6.11)

- the peak abundance estimates at Willamette Falls (Willamette stratum; Figure A6.9) appears to correspond with adult counts higher up in that same basin, at both Upper Bennett and Leaburg dams (Willamette stratum; Figure A6.4)
- similar trends in abundance were not apparent across all strata. For example, the apparent correspondence in peak abundance indices at Bonneville Dam during 2016 (Figure A6.3) and the Mid Columbia stratum (Figures A6.10 – A6.11) did not appear to correspond with abundance estimates for adult Pacific Lamprey at Willamette Falls (Willamette stratum) during that same year (Figure A6.9)
- abundance of adult Pacific Lamprey varied cyclically across years, peaking every five to 14 years at dams, every five to eight years in spawning ground surveys, and every four to 11 years in mark/recapture studies. Taken together, the periodicity of peak abundance of adult Pacific Lamprey was four to 14 years, depending upon the abundance index and location
- the three strata east of the Cascades (Mid Columbia, Lower Snake, and Upper Snake) lack abundance data beyond adult counts at mainstem Columbia and Snake river dams (Figure A6.3).

Table A6.7. Correlation coefficients for the number of adult Pacific Lamprey counted or estimated on a particular project during years when counts or estimates coincided. Data from Bonneville and Winchester Dams prior to 1993 was excluded, as the other data sources were not recording data during these early years. Correlations ≥ 0.50 with probabilities ≤ 0.10 are considered to be both strong and statistically significant (indicated in **bold**). SGS = spawning ground surveys; RSC = Rogue/South Coast; CST = Coastal; LC = Lower Columbia, and WI = Willamette.

Project	Population stratum	BON counts	WIN counts	GR counts	Coastal SGS	Lower Columbia SGS
Bonneville Dam (BON) counts	Mainstem Columbia [a]	–	–	–	–	–
Winchester Dam (WIN) counts	CST	0.04	–	–	–	–
Gold Ray Dam (GR) counts	RSC	0.23	-0.28	–	–	–
OASIS SGS	CST	**0.53**	**0.74**	–[b]	–	–
OASIS SGS	LC	-0.01	0.29	–[c]	**0.87**	–
OASIS SGS	WI	0.15	**0.77**	–[c]	**0.67**	0.47

[a] Not a population stratum.

[b] Too few overlapping years to make correlation.

[c] No overlapping years to make correlation.

Appendix 7. Supporting information for assessing connectivity

This appendix presents details on the Methods, Results, and Conclusions for assessing the connectivity criterion. The main conclusions are presented in Chapter 3. Connectivity was assessed for Pacific Lamprey through the identification and enumeration of potential artificial obstructions.

METHODS

The goal for this criterion was to assess, at a large scale, key potential artificial obstructions to anadromy of Pacific Lamprey. The approach for this criterion was to assess the number of dams within and downstream of a population stratum that may block the anadromous life cycle.

Dams were identified on 5th order and larger streams using the U. S. Geological Survey's National Hydrography Dataset plus stream GIS layer and ODFW's Fish Passage Barrier data layer. Dams within 200 m (656 ft) of the stream layer were identified and enumerated when the barrier layer was overlaid onto the stream layer. Dams were then visually inspected on an aerial imagery reference layer to verify whether these existed in the main stream channel and could thus present a potential barrier to Pacific Lamprey. The actual passage of lamprey at a particular dam was not evaluated. Future assessment of passage efficiency at these dams would greatly strengthen the utility of these analyses. Dams with the aforementioned characteristics were tallied both within a particular stratum and downstream of that stratum. Tallies within and downstream of a stratum were summed. Summed tallies were translated into categorical scores ("connectivity scores"), where 1 = most connected (least dams); 0.75 = moderately connected; 0.5 = less connected, and 0 = disconnected (most dams).

RESULTS AND DISCUSSION

The identification and enumeration of key potential artificial obstructions that may disrupt anadromy for Pacific Lamprey provided a coarse assessment of connectivity. Dams that were identified with the methods detailed above ranged in size from the large, high-head Snake and Columbia River dams down to relatively small, low-head water diversion dams. Some major dams were left out of this assessment via the aforementioned protocol — for example, in the Willamette stratum, Green Peter, Blue River, Cougar, Trail Bridge, and Hills Creek dams were excluded as these are on streams smaller than 5th order. However, this assessment provided a measure of connectivity that was relative among strata (Table A7.1; Figure A7.1). The tally of major dams within and downstream of each stratum indicates that the Coastal stratum is the most connected (fewest major dams), whereas the Upper Snake is the least connected (most dams) for Pacific Lamprey (Table 3.4).

Table A7.1. Total number of key potential artificial obstructions at 5th order and larger streams that may disrupt anadromy. Table A7.2 provides an inventory of all 83 of these dams.

Population strata	In population strata	Downstream	Total
Rogue/South Coast	5		5
Coastal	1		1
Lower Columbia	5		5
Willamette	16		16
Mid Columbia	29	1	30
Lower Snake	0	8	8
Upper Snake	27	8	35

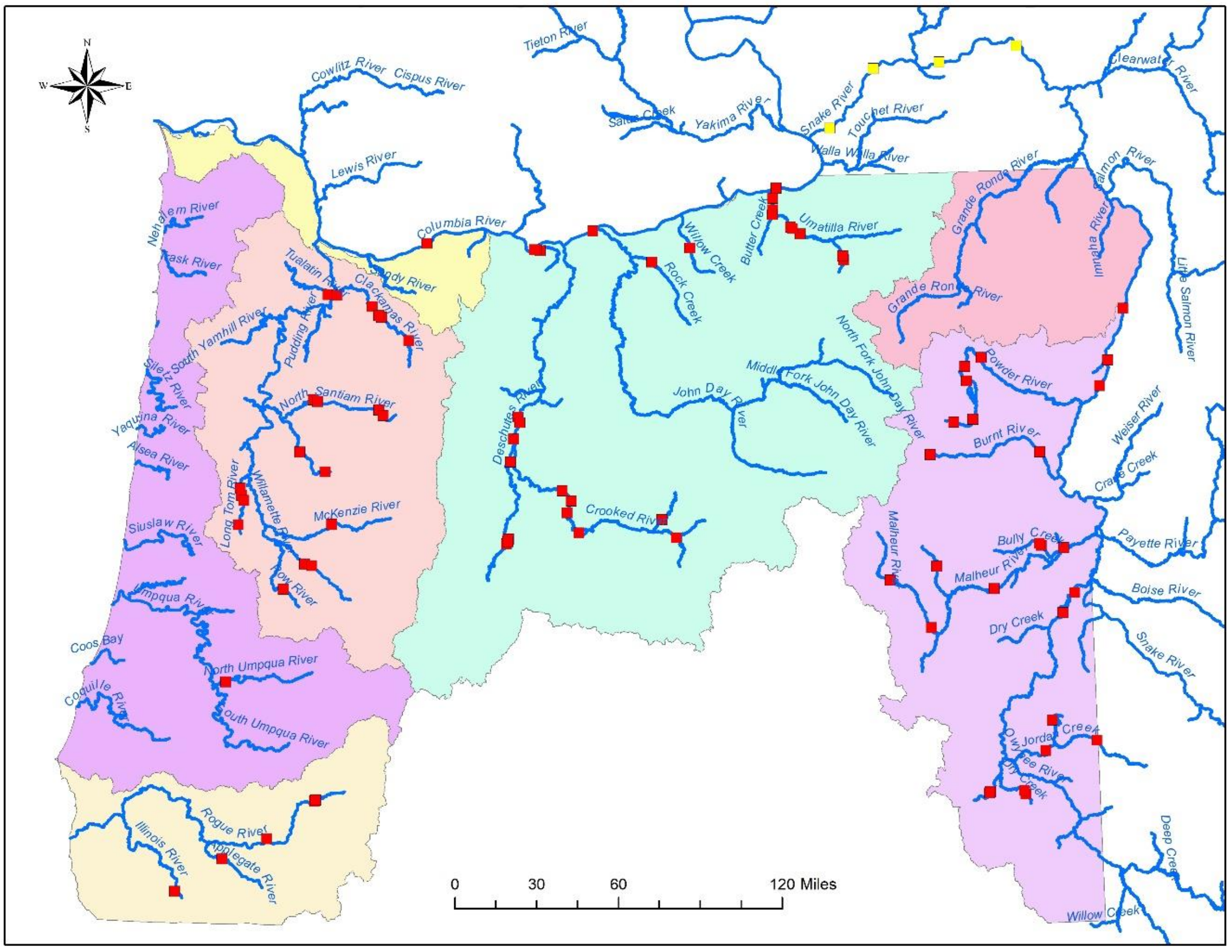

Figure A7.1. Map of Oregon displaying streams at the 5th order and higher scale. Starting in the lower left corner and moving clockwise the seven population strata (indicated by different colors) include the Rogue/South Coast, Coastal, Lower Columbia, Willamette, Mid Columbia, Lower Snake, and Upper Snake. Red squares = dams from ODFW's Fish Passage Barrier database. Yellow squares = dams in the Snake River, outside of Oregon; these four dams were added to the results (Tables A7.1 and A7.2).

Table A7.2. Eighty-three key potential artificial obstructions to anadromy of Pacific Lamprey at the level of 5th order streams and higher.

Species Management Unit	Location	Dam	River
Coastal	In population stratum	Winchester Dam	North Umpqua River
Lower Columbia	In population stratum	Three Lynx Powerhouse Dam	Clackamas River
Lower Columbia	In population stratum	River Mill Dam	Clackamas River
Lower Columbia	In population stratum	North Fork Dam (Clackamas)	Clackamas River
Lower Columbia	In population stratum	Faraday Diversion Dam (Cazadero)	Clackamas River
Lower Columbia	In population stratum	Bonneville Dam	Columbia River
Lower Snake	Downstream	Lower Granite Dam	Snake River
Lower Snake	Downstream	Little Goose Dam	Snake River
Lower Snake	Downstream	Lower Monumental Dam	Snake River
Lower Snake	Downstream	Ice Harbor Dam	Snake River
Lower Snake	Downstream	Bonneville Dam	Columbia River
Lower Snake	Downstream	The Dalles Dam	Columbia River
Lower Snake	Downstream	John Day Dam	Columbia River
Lower Snake	Downstream	McNary Dam	Columbia River
Mid Columbia	Downstream	Bonneville Dam	Columbia River
Mid Columbia	In population stratum	Broun/Garton Diversion	Birch Creek
Mid Columbia	In population stratum	Peterson Dam	Birch Creek
Mid Columbia	In population stratum	The Dalles Dam	Columbia River
Mid Columbia	In population stratum	John Day Dam	Columbia River
Mid Columbia	In population stratum	McNary Dam	Columbia River
Mid Columbia	In population stratum	Opal Springs Diversion Dam [a]	Crooked River
Mid Columbia	In population stratum	Peoples Dam	Crooked River
Mid Columbia	In population stratum	Rice Baldwin Dam	Crooked River
Mid Columbia	In population stratum	Unknown	Crooked River
Mid Columbia	In population stratum	Prineville Reservoir (Bowman)	Crooked River
Mid Columbia	In population stratum	Twin Buttes Dam	Crooked River
Mid Columbia	In population stratum	Steidl Dam (Tumalo Irrigation District Div. Dam)	Deschutes River
Mid Columbia	In population stratum	Shevlin-Hixon Dam	Deschutes River
Mid Columbia	In population stratum	Pelton Regulating Dam	Deschutes River
Mid Columbia	In population stratum	Pelton Dam	Deschutes River
Mid Columbia	In population stratum	Round Butte Dam	Deschutes River
Mid Columbia	In population stratum	North Unit Diversion Dam	Deschutes River
Mid Columbia	In population stratum	Bend Hydro (Mirror Pond)	Deschutes River
Mid Columbia	In population stratum	Tenold Diversion Dam	Fifteenmile Creek
Mid Columbia	In population stratum	Seufert's Dam	Fifteenmile Creek
Mid Columbia	In population stratum	Unknown	North Fork Crooked River
Mid Columbia	In population stratum	Marricks Dam	Rock Creek
Mid Columbia	In population stratum	Westland Canal Diversion	Umatilla River

Mid Columbia	In population stratum	Furnish Canal Diversion	Umatilla River
Mid Columbia	In population stratum	Boyd Hydro Dam[b]	Umatilla River
Mid Columbia	In population stratum	Cold Springs Diversion Dam	Umatilla River
Mid Columbia	In population stratum	Maxwell Diversion Dam	Umatilla River
Mid Columbia	In population stratum	Threemile Falls Diversion Dam	Umatilla River
Mid Columbia	In population stratum	Cheney Dam	Willow Creek
Rogue/South Coast	In population stratum	Murphy Dam	Applegate River
Rogue/South Coast	In population stratum	Pomeroy Dam	Illinois River
Rogue/South Coast	In population stratum	Cole Rivers Hatchery Diversion Dam	Rogue River
Rogue/South Coast	In population stratum	Lost Creek Reservoir (COE)	Rogue River
Rogue/South Coast	In population stratum	Gold Hill Irrigation District Diversion Dam	Rogue River
Upper Snake	Downstream	Lower Granite Dam	Snake River
Upper Snake	Downstream	Little Goose Dam	Snake River
Upper Snake	Downstream	Lower Monumental Dam	Snake River
Upper Snake	Downstream	Ice Harbor Dam	Snake River
Upper Snake	Downstream	Bonneville Dam	Columbia River
Upper Snake	Downstream	The Dalles Dam	Columbia River
Upper Snake	Downstream	John Day Dam	Columbia River
Upper Snake	Downstream	McNary Dam	Columbia River
Upper Snake	In population stratum	Bully Creek Diversion Dam	Bully Creek
Upper Snake	In population stratum	Bully Creek Dam	Bully Creek & Malheur River
Upper Snake	In population stratum	Unity Reservoir	Burnt River
Upper Snake	In population stratum	Cow Lake (Lower)	Cow Creek
Upper Snake	In population stratum	Anderson-Lower (Malheur)	Crooked Creek
Upper Snake	In population stratum	Jaca Dam	Crooked Creek
Upper Snake	In population stratum	Blevin Dam	Dry Creek
Upper Snake	In population stratum	Rock House Reservoir (Malheur)	Dry Creek
Upper Snake	In population stratum	Arock Diversion Dam	Jordan Creek
Upper Snake	In population stratum	Antelope Reservoir Diversion	Jordan Creek
Upper Snake	In population stratum	Reclamation Ditch	Malheur River
Upper Snake	In population stratum	Nevada Dam	Malheur River
Upper Snake	In population stratum	Harper Diversion	Malheur River
Upper Snake	In population stratum	Warm Springs Reservoir (USBR)	Middle Fork Malheur River
Upper Snake	In population stratum	Agency Valley Dam	North Fork Malheur River
Upper Snake	In population stratum	Perkins Dam (2)	North Powder River
Upper Snake	In population stratum	Owyhee	Owyhee River
Upper Snake	In population stratum	Owyhee Ditch Dam	Owyhee River
Upper Snake	In population stratum	Thief Valley Dam	Powder River
Upper Snake	In population stratum	Mason Dam	Powder River
Upper Snake	In population stratum	Baker Valley I.D. Equalizing Pond	Powder River
Upper Snake	In population stratum	Smith Ditch	Powder River

Upper Snake	In population stratum	Shaw-Stewart Ditch	Powder River
Upper Snake	In population stratum	Metsker Diversion	Sisley Creek
Upper Snake	In population stratum	Hells Canyon Dam	Snake River
Upper Snake	In population stratum	Oxbow Hydro Dam (Snake)	Snake River
Upper Snake	In population stratum	Brownlee Dam	Snake River
Upper Willamette	In population stratum	Monroe Dam and Fishway	Long Tom River
Upper Willamette	In population stratum	Stroda Dam	Long Tom River
Upper Willamette	In population stratum	Ferguson Creek Drop Structure	Long Tom River
Upper Willamette	In population stratum	Fern Ridge	Long Tom River
Upper Willamette	In population stratum	Leaburg Dam	McKenzie River
Upper Willamette	In population stratum	Dexter	Middle Fork Willamette River
Upper Willamette	In population stratum	Lookout Point Dam	Middle Fork Willamette River
Upper Willamette	In population stratum	Lower Bennett Diversion Dam	North Santiam River
Upper Willamette	In population stratum	Upper Bennett Diversion Dam	North Santiam River
Upper Willamette	In population stratum	Big Cliff Dam	North Santiam River
Upper Willamette	In population stratum	Detroit Reservoir	North Santiam River
Upper Willamette	In population stratum	Dorena Dam	Row River
Upper Willamette	In population stratum	Foster Reservoir	South Santiam River
Upper Willamette	In population stratum	Lebanon Dam	South Santiam River
Upper Willamette	In population stratum	Oswego Dam	Tualatin River
Upper Willamette	In population stratum	Willamette Falls	Willamette River

[a] Fish passage restoration for salmon and steelhead was initiated on the Opal Springs Diversion Dam this year but it is not known if the ladder will be lamprey friendly.

[b] The Boyd Hydro Dam is currently inoperative and the hydro license and hydro water right have been terminated.
Jackson and Moser (2012) showed adult lamprey passage increased to 92% following termination of the Boyd hydro license and removal of concrete weirs between the stations.

Appendix 8. Supporting information for limiting factors

LIMITING FACTORS

Table A8.1 presents the limiting factor ranking by ODFW for Pacific Lamprey that was used to generate a ranking (Table 5.2) in a process described in Chapter 5.

Table A8.1. Primary limiting factors ("❶" in red cells), secondary limiting factors ("❷" in orange cells), and unknown limiting factors ("?" in salmon-colored cells) for Pacific Lamprey. Gray cells indicate the lack of primary, secondary, or unknown limiting factors. Secondary limiting factors are believed to contribute to a lesser degree than primary limiting factors to the gap between current and desired status. Limiting factors were identified by population stratum and ranked by best professional judgement by ODFW. Footnotes indicate instances where a few watersheds drove the ranking for an entire stratum.

		Pacific Lamprey (*ODFW*)						
Management Category	**Limiting Factor**	Rogue/South Coast	Coastal	Lower Columbia	Willamette	Mid Columbia	Lower Snake	Upper Snake
Water Quality	Temperature	2		1	2	2	2	?
	Sedimentation			1	2		2	?
	Toxic Pollutants	?	?	?	?	?	?	?
	Other							
Water Quantity	Low	2[a]			2	2	2[d]	2
	Altered Hydrology	2[a]			2	2	2[d]	2
Habitat Access (Passage)	Inundation							
	Upstream Passage	1[a]	1[c]	?	1	1	1	1
	Downstream Passage	1[a]	1[c]	?	1	1	1	1
Physical Habitat	Instream Structure						2	
	Substrate							
	Peripheral Connection						2	
Other Species	Predation: Pinnipeds	?	?	1	1			
	Predation: Birds			1	?	?		
	Predation: Non-native fishes		1[b]	1	?	2	?	?
	Competition							
	Hybridization							
	Food Source							
	Disease							
	Other							
Direct Interactions	Release							
	Take		?	?	?	?		

[a] Ranking driven by the Illinois, Middle Rogue, Applegate, and Upper Rogue basins;
[b] Ranking driven by the Umpqua, Tenmile Lakes, Coos, and Coquille basins;
[c] Ranking driven by the Umpqua Basin;
[d] Ranking driven by the Lookingglass, Upper Grande Ronde, and Catherine Creek basins.

Water quality

Table A8.2 presents causes of traditionally-recognized impairments to water quality in Oregon. Table A8.3 includes toxic pollutants.

Table A8.2. Causes of water quality impairment in assessed streams and rivers in Oregon, as of the most recent assessment in 2006 (per ODEQ 2017). The top eight causes of impairment are shown in order of descending amount of river miles impacted. Another 133 causes of water quality impairment for ≤1,360 miles of stream and river habitat were also identified (not shown).

Cause of impairment	Cause of impairment	Miles impaired or threatened
Water temperature	Temperature	17,253
Sedimentation / siltation	Sediment	11,997
Nutrients	Nutrients	11,273
Nutrients – eutrophication	Nutrients	10,508
pH	pH/acidity/caustic conditions	5,370
Dissolved oxygen	Organic enrichment/oxygen depletion	4,261
Fecal coliform	Pathogens	2,687
Escherichia coli	Pathogens	2,359

Table A8.3. Toxic pollutants that can impact lampreys and other aquatic fauna. This list is not comprehensive.

Contaminants	Examples	Sources of input into lamprey habitats	References
Pharmaceutical and personal care products (PCP)	Antiseptics, detergents, antibiotics, bioactive food supplements, cosmetics, fragrances, insect repellent, and sunscreen	Municipal wastewater discharge	Reviewed in IMST (2010)
Halogenated flame retardants	Dechlorane plus, pentabromotoluene, and polybrominated-diphenyl-ethers (PBDEs) in manufactured goods	Municipal wastewater discharge; industrial manufacturing facilities	Reviewed in IMST (2010); Nilsen et al. (2015)
Alternative flame retardants	1,2-bis(2,4,6-tribromophenoxy) ethane	Municipal wastewater discharge; industrial manufacturing facilities	Nilsen et al. (2015)
Polycyclic aromatic hydrocarbons (PAHs)	Compounds in roofing tar, asphalt, creosote, gasoline, etc.	Runoff from treated structures, fuel spills, industrial effluent	Reviewed in IMST (2010)
Nanomaterials	Used in industry and technology	Municipal wastewater and incineration of waste products containing nanomaterials	Reviewed in IMST (2010); Gottschalk and Nowack (2011)
Chemicals used in manufacture of PCPs and plastics	Phthalate compounds and bisphenol A	Landfills and leaching into groundwater, litter, municipal wastewater discharge	Reviewed in IMST (2010)
Mercury		Natural and human-caused sources	Nilsen et al. (2015)
Legacy use pesticides	Chlordanes, DCPA, DDD, DDE, DDT, dieldrin, endosulfans, hexachlorobenzene, nonachlors, octachlorostyrene, oxychlordane, pentachloroanisole, pentachloronitrobenzene, polychlorinated biphenyls (PCBs)	Residuals in environment remaining from legacy use	Nilsen et al. (2015)
Currently used pesticides	Benfluralin, chlorpyrifos, cyfluthrin, cyhalothrin, dessulfinyl fipronil, fipronil, fipronil sulfide, oxyfluorfen, tefluthrin, tetradifon, trifluralin	Runoff	Nilsen et al. (2015)

Habitat access

Upstream migrating adult lampreys

Artificial obstructions limit the abundance and distribution of Pacific Lamprey (and Western River Lamprey), and the provision of marine-derived nutrients from their spawned-out carcasses to river ecosystems (CRITFC 2011; Luzier et al. 2009, 2011; Clemens et al. 2017a). Passage requirements for adult lampreys are best understood where extensively researched for Pacific Lamprey, at mainstem dams in the Snake and Columbia rivers (e.g., Moser and Mesa 2009; Keefer et al. 2009a, 2010, 2012, 2013; Moser et al. 2015a; PLTWG 2017). Wherever passage is a concern for Pacific Lamprey, it is likely that it will also be a concern for the smaller-bodied Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey. In addition, owing to their relatively small adult body sizes (Table 2.1), Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey likely experience challenges to upstream passage at some artificial obstructions that Pacific Lamprey readily pass. For example, large adult Pacific Lamprey can pass dams and migrate upstream more readily than relatively small adult Pacific Lamprey (Keefer et al. 2009a, 2013; Clemens et al. 2010; Hess et al. 2014); therefore, the smaller-bodied adults of the other three lampreys have lower likelihoods of ascending particular artificial obstructions than Pacific Lamprey.

Unlike Pacific salmon and steelhead, adult Pacific Lamprey cannot jump; therefore, perched culverts can impede upstream passage (Streif 2009; USFWS 2010). Pacific Lamprey also cannot negotiate 90° angles, cannot cue to turbulent flows, nor swim long distances without resting areas with attachment surfaces for their oral discs. Pacific Lamprey cannot consistently swim at water velocities > 3 fps for prolonged amounts of time. Taken together, these traits make passage of Pacific Lamprey through traditional fish ladders problematic (PLTWG 2017). This is exemplified by the low counts of adult Pacific Lamprey at mainstem dams on the Columbia and Snake rivers. Few adults make it to Lower Granite Dam in the Snake River (Figure A6.3). Previously (1997 – 2000), only 38 – 47% of radio-tagged, adult Pacific Lamprey successfully passed Bonneville Dam, and 50 – 82% successfully passed The Dalles Dam (Moser et al. 2002). More recently, passage efficiencies have either increased or decreased slightly at these two dams (Keefer et al. 2013; Clabough et al. 2015). Farther upstream at McNary Dam, passage efficiency for adult Pacific Lamprey was estimated to be 65 – 75% (Keefer et al. 2013). Thousands of other artificial obstructions throughout Oregon have not been subjected to similar assessments. Of the relatively few subbasins examined in Coastal Oregon, potentially thousands of artificial obstructions exist that require assessment of passability (Starcevich and Clements 2013). Specific passage needs for adult lampreys in culverts are not well understood (Stillwater Sciences 2014; Clemens et al. 2017a) and passage at tidegates has not yet been studied. Adapting and providing downstream passage for the progeny of adult Pacific Lamprey that have successfully migrated past artificial obstructions has lagged (Mesa and Copeland 2009). In some cases the provision of upstream migration for adult lampreys at artificial obstructions may be futile to population recruitment because of impediments to downstream migrations of their progeny by those same (and potentially other) artificial obstructions.

Outmigrating larval and juvenile lampreys

Larval and juvenile lampreys are thought to be generally passive drifters with weak swimming capabilities (Chapter 2, Appendix 3). Therefore movements and distribution of these life stages are subjected to river hydraulics, particularly at high flows from freshets or large rivers (Appendix 3). This can result in their entrainment into artificial obstructions or impingement onto the screens of these obstructions. Screen material, mesh size, screen type, approaching flow and sweeping flow velocities all influence the likelihood that larval and juvenile lampreys will become entrained or impinged (Rose and Mesa 2012; Crandall et al. 2015). A lack of screening or inadequate screening at thousands of water diversions in the Pacific Northwest and across Oregon may result in the decimation of many year classes and a substantial loss of lampreys (CRITFC 2011; Crandall et al. 2015).

Very small larvae (< 2.5 in body length; Figure 2.4A) are particularly susceptible to entrainment into water diversions (Moser et al. 2015a; Clemens et al. 2017a). Therefore a 3/32 in mesh size criteria for salmonids is too large for very small larval lamprey (CRITFC 2011). Slow-moving, depositional waters with fine substrate (silt and sand) within the proximity of fish screens may attract larvae (Clemens et al. 2017a) that can eventually become entrained into these diversions. Larval lampreys that become entrained into water diversions can be pumped onto agricultural fields or end up in irrigation ditches that dry out, resulting in mortalities (CRITFC 2011; Crandall et al. 2015).

Traveling screens of large dams in the Snake and Columbia rivers that are designed to bypass juvenile salmonids downstream can impinge and kill larval and juvenile lampreys (Moursund et al. 2003). Approach velocities ≥ 1.6 fps at screens at these dams increase the chances that larval and juvenile lampreys will become impinged (USFWS 2010).

Physical habitat

Examples of physical habitat problems are described below.

Rogue/South Coast stratum.— Basins in this stratum are relatively steep in gradient, and have confined channels and coarse geologies with small estuaries that are often bar-bound (closed) during the summer. Very little low gradient, depositional areas occur in watersheds within the Rogue/South Coast stratum. These characteristics may translate into proportionally less habitat for larval burrowing and rearing in this stratum.

Coastal stratum.— In the Umpqua Basin, the substrate is limiting for spawning and rearing of lampreys.

In the Mid and North coast districts, a lack of habitat complexity is a limiting factor, both in-stream and in estuaries. In particular, a lack of large woody debris in constrained sections and in estuaries was cited by ODFW staff as lacking and probably being necessary to increase retention of larval lamprey to allow sufficient time for osmoregulatory processes to develop whilst hiding from predators (Clemens 2017). Within the Coastal stratum off-channel refuges (overwintering habitat) from high river flows are lacking. These overwinter habitats are critical for young Coho Salmon, and they may also be critical for young lampreys.

Willamette stratum.— The mainstem Willamette River was subjected to snag removal, impoundment, flow regulation, and subsequent channelization that correlate in time with reduced harvest of Pacific Lamprey at Willamette Falls (Clemens et al. 2017a). It has been hypothesized that dynamic, free-flowing rivers and restoration of natural ecological functions in streams and floodplains can benefit lamprey (Clemens et al. 2017a).

Mid Columbia stratum.— Significant portions of the John Day, Umatilla, and Walla Walla, and Willow Creek basins have been straightened and leveed.

Lower Snake stratum.— The Grande Ronde River was subjected to draining and development of a large wetland in the Grande Ronde valley. The upper mainstem Grande Ronde and Catherine Creek have experienced significant stream and floodplain degradation. Significant frequencies and occurrences of splash-damming in the early 1900s scoured out fine substrates and gravel. Riparian vegetation has been removed, the river channels simplified, and fine sediments removed in the Grande Ronde River upstream of La Grande.

Upper Snake stratum.— Some channelization, leveeing, and diking occurred in parts of some basins in the Upper Snake stratum.

Other species

Predation

Smallmouth Bass introductions, distribution, and predation in Oregon are described below.

Coastal population stratum.— In the Coquille Basin, Smallmouth Bass were illegally introduced and established by at least 2009. Since then, Smallmouth Bass in the Coquille have increased significantly and greatly expanded their distribution from near the end of salinity in tidewater up into the South Fork Coquille and Middle Fork Coquille (G. Vonderohe, ODFW pers. comm.). In the Umpqua Basin, the likelihood of introduction in the early 1960s, and subsequent distribution of Smallmouth Bass coincided with a decline in counts of adult Pacific Lamprey migrating past Winchester Dam in the North Umpqua River (Schultz et al. 2017). Nearly 2,000 larval lamprey were estimated to have been consumed by Smallmouth Bass within a single segment of a single tributary (Elk Creek) to the Umpqua River, near the town of Elkton, Oregon (Schultz et al. 2017). This led to the conclusion that Smallmouth Bass "*…may negatively affect larval lamprey populations*" (Schultz et al. 2017). Anglers have reported Smallmouth Bass regurgitating "worms" when caught, which are likely larval lamprey (J. Brandt and G. Huchko, ODFW pers. comm.). This information led to the ranking of non-native fish as a primary limiting factor in the Coastal stratum (Table 5.2).

Mainstem Columbia.— Within the mainstem Columbia, during 2006 – 2016, the finding of lampreys in diet samples of 11,126 non-native fishes was 0.1 and 0.2% of Smallmouth Bass and Walleye, respectively (M. Barr, Columbia River Predation Studies, ODFW, unpubl. data)[4].

Willamette stratum.— In 1923, Smallmouth Bass were introduced into the Willamette River and they have since increased substantially in abundance and distribution (Carey et al. 2011). In 2016, in the lower reaches of two tributaries to the South Santiam River (subbasin in the Willamette River), ODFW field staff observed hundreds of Smallmouth Bass near lamprey redds (M. Sinnott, ODFW, pers. comm.). It is unknown whether the Smallmouth Bass were eating larval lamprey that emerged from the redds.

Mid Columbia stratum.— In the Deschutes River, Smallmouth Bass are commonly found in the lower 10 miles. Smallmouth Bass are now found up to at least river mile 26 in the Deschutes River. In the John Day Basin, introduction occurred in 1971, and that population has expanded into the North Fork John Day River (Carey et al. 2011; Lawrence et al. 2012), and well into the Middle Fork John Day River (B. Smith, ODFW, pers. comm.). Smallmouth Bass are also present in the Umatilla River Basin (B. Duke, ODFW pers. comm.).

Lower Snake stratum.— Smallmouth Bass are present in the lower Grande Ronde and Imnaha rivers (T. Bailey, J. Yanke, and K. Bratcher, ODFW pers. comm.).

Upper Snake stratum.— Smallmouth Bass and Channel Catfish are present in the Hells Canyon Complex reservoirs (Brownlee, Oxbow and Hells Canyon reservoirs) and the Snake River upstream of Brownlee Reservoir. The upper Malheur Basin has warmwater fisheries. Impoundments in these systems and other habitat degradations and water removals have led to slow-moving, warmwater conditions that are suitable for non-native Smallmouth Bass (Sanderson et al. 2009; Carey et al. 2011).

Direct interactions

Take

Harvest

Table A8.4 presents information on harvest of adult Pacific Lamprey. Figure A8.1 shows the harvest of adult Pacific Lamprey at Willamette Falls.

Table A8.4. Available data for harvest numbers of adult Pacific Lamprey from reported harvest to the Oregon Department of Fish and Wildlife and harvest estimates at Willamette Falls by the Confederated Tribes of the Warm Springs Reservation of Oregon. Harvest rate was calculated as the percentage of the total abundance of lamprey at the harvest location, as estimated by marking and recapturing lamprey.

	Harvest Locations			
	South Fork Coquille	**Willamette Falls**	**Cushing Falls**	**Sherars Falls**
Basin	South Fork Coquille River	Willamette River	Fifteenmile Creek	Deschutes River
Population stratum	Coastal	Willamette	Mid Columbia	Mid Columbia
Harvest type	Tribal	Tribal, Personal use	Tribal	Tribal
Yrs of harvest estimates	2011 – 18	2010 – 18	2011 – 14; 2016	2004 – 15; 2017
Ave. annual harvest no. (range)	25 (0 – 40)	4,328 (1,547 – 8,263) [a]	194 (83 – 390) [c]	1,715 (345 – 5,190) [c]
Ave. harvest rate (range)	Not estimated	3.0% (1.2 – 4.8%) [a, b]	7.5% (3.2 – 12.0%) [c]	19.1% (10.0 – 28.5%) [c]

[a] ODFW harvest records of reported tribal harvest and personal use harvest.

[b] Baker (2016); Baker and McVay (2015, 2016, 2017, 2018, and 2019).

[c] Baker et al. (2015); Baker (2016); Johnsen and Baker (2017, 2018).

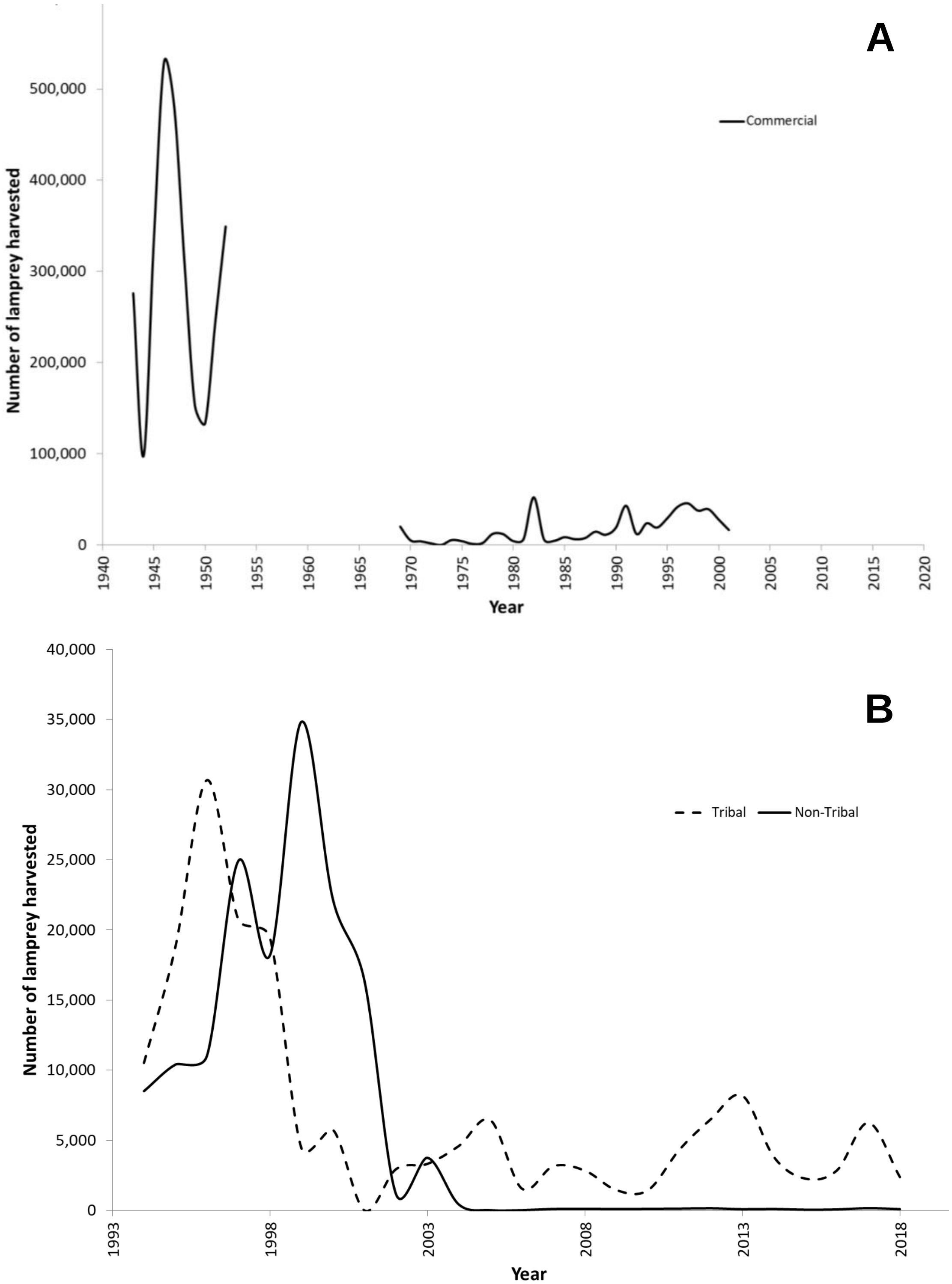

Figure A8.1. Harvest at Willamette Falls (Lower Columbia stratum), according to historical and permitted harvest data reported to the Oregon Department of Fish and Wildlife. (**A**) Commercial harvest occurred 1943 – 2001. Tribal harvest was considered commercial until 2001. (**B**) Tribal and non-tribal (personal use) data were tracked beginning in 1994. Note the different harvest scales between A and B.

Scientific take

Table A8.5 presents the numbers of lampreys taken for permitted scientific take during 2002 – 2017. Table A8.6 presents the numbers of mortalities for permitted scientific take during 2002 – 2017.

Table A8.5. Numbers of lampreys taken for permitted scientific take in Oregon during 2002 – 2017. Also shown is the percentage of mortalities. The final column is computed as: {(intentional mortalities + unintentional mortalities) ÷ (take + unintentional mortality)] X 100. PL = Pacific Lamprey; WRL = Western River Lamprey; WBL = Western Brook Lamprey; LU = Lamprey of unknown species.

Species	Take	Intentional mortality	Indirect (unintentional) mortality	Mortalities (%) of entire take
PL	134,028 [a]	4,889	12,606	**11.9**
WRL	279	14	-	**5.0**
WBL	11,420	385	1,317	**13.4**
LU	53,577	3,333	719	**7.5**
Grand Total	*199,304*	*8,621*	**14,642**	**10.9**

[a] This number has been corrected to remove the number of adult Pacific Lamprey translocated by the CTGR from below Willamette Falls to above Fall Creek Dam in the Middle Fork Willamette.

Table A8.6. Numbers of lamprey mortalities for permitted scientific take in Oregon during 2002 – 2017, by species and population stratum. Although the ocean and mainstem Columbia are not strata, the take for lampreys in these areas is shown for convenience. The 302 Western River Lamprey in the Willamette is surprising; these have likely been misidentified Western Brook Lamprey.

	Pacific Lamprey	Western River Lamprey	Western Brook Lamprey	Lamprey species unknown	Grand Total
Ocean	68	-	-	6	*74*
Coastal	12,762	-	1,314	3,143	*17,219*
Rogue/South Coast	373	-	-	54	*427*
Mainstem Columbia	362	-	-	212	*574*
Lower Columbia	577	14	65	374	*1,030*
Willamette	3,208	302	21	247	*3,778*
Mid Columbia	145	-	-	16	*161*
Grand Total	*17,495*	*316*	*1,400*	*4,052*	*23,263*

Take and release

Translocation and broodstock collection

Member tribes of the Columbia River Inter-Tribal Fish Commission (CRITFC) and the Confederated Tribes of the Grand Ronde (CTGR) actively translocate adult Pacific Lamprey within Oregon. The Confederated Tribes of the Umatilla Indian Reservation have been translocating adult Pacific Lamprey the longest — since 1999 (Ward et al. 2012). Some tribes may continue to translocate indefinitely, until Pacific Lamprey are recovered (CRITFC 2011). In a sequential, phased approach, CRITFC and its member tribes plan to use the results from research on translocated adults (and releases of hatchery lamprey) "…*to inform development of restoration actions*" (CRITFC et al. 2018).

The Tribal Pacific Lamprey Restoration Plan (CRITFC 2011) defines the guidelines by which the four member tribes of CRITFC, including the Confederated Tribes of the Warm Springs Reservation of Oregon, Yakama Nation, Confederated Tribes of the Umatilla Indian Reservation, and the Nez Perce Tribe determine the relative proportion of adult Pacific Lamprey to be collected for translocation. Donor sources for Pacific Lamprey include the three lowest dams in the mainstem Columbia River (Bonneville, The Dalles, and John Day), with a backup option of Willamette Falls in the Willamette River. These guidelines include taking up to 8% (2% per year, per tribe) of a two-year running average of the total counts of Pacific Lamprey passing Bonneville Dam (day and night time counts, counts of passage via lamprey passage structures, and trapping). The allocation had been 4% (1% per year, per tribe; CRITFC 2011), but this was increased in 2017 (Aaron Jackson, CTUIR, pers. comm.; Ralph Lampman, Yakama Nation, pers. comm.; Laurier Porter, CRITFC, pers. comm.). At The Dalles and John Day dams, tribal guidelines for CRITFC tribes stipulate that the collection of adult Pacific Lamprey will not exceed 10% of the two-year running average of the total abundance index (estimated counts) past each of these dams. Additional lamprey may be collected from dewatering at all three Columbia River dams (CRITFC 2011). In 2017, CRITFC tribes determined that collection of adult Pacific Lamprey at Bonneville Dam cannot be greater than 50% of the total collection of lamprey at all dams (Laurie Porter, CRITFC, pers. comm.). Finally, the tribal guidelines for translocation stipulate that lamprey to be translocated will be screened for disease pathogens, and that "*Regulatory requirements will be addressed (NEPA, ESA, fish collection permits, USACE FPOM, etc.), if applicable*" (CRITFC 2011). Release locations for lamprey originating from the Columbia River dams occur in Washington, Idaho, and northeast Oregon, in tributaries to the lower and upper Snake River, and tributaries to the mid-Columbia River (Ward et al. 2012; CRITFC et al. 2018).

The CTGR have been translocating in the Willamette Basin since 2013, and plan on continuing to do so until the year 2020. The CTGR has been treating their translocations as a scientific study and they have been operating under ODFW scientific take permit. From the numbers reported by the CTGR to ODFW, it is estimated that < 0.01% of all adult Pacific Lamprey at Willamette Falls (Table A6.6) have been translocated by the CTGR between 2013 and 2017. The release location of lamprey taken from Willamette Falls is into Fall Creek, a tributary to the Middle Fork of the Willamette River.

Appendix 9. Complex, large-scale threats

This appendix presents supplemental information on complex, large-scale threats that are discussed in Chapter 5. This supplemental information includes the predicted effects and consequences of climate change (Table A9.1) and examples of complex, cumulative, and potentially synergistic effects of climate change (Table A9.2).

Table A9.1. Effects associated with climate change, and the predicted consequences of these effects on stream environments and **biota**, including lampreys, in the Pacific Northwest in general. The effects are generally listed in order of effects to land-based ecosystems, then rivers, and then the ocean. Numbering is used to show the cumulative and synergistic nature of associations among effects.

Effect	Environmental and biological results	References
1. Increased intensity of wildfires	Exacerbate #4, 8, 20, 23, and 24	ISAB (2007); Mote et al. (2014); Williams et al. 2015a)
2. Increased droughts	Exacerbate #1, 3, 4, 6, 9, 10, 11, and 13	ISAB (2007); Williams et al. (2015a)
3. Increased insect pests / increase in numbers of diseased trees at subalpine elevations	Exacerbate #4	Mote et al. (2014)
4. Decreased natural vegetation	Increased erosion and sedimentation into streams; reduced shading of stream from solar radiation; reduced large woody debris recruitment into streams; changed dynamics between water retention and released between groundwater and stream water	Mote et al. (2014); Williams et al. (2015a)
5. Increased in invasive vegetation	Exacerbate #4	Mote et al. (2014)
6. Change in precipitation patterns and reductions in mountain snowpack	Greater precipitation, especially in winter; less precipitation in the summer; greater precipitation falling as rain (vs. snow); less snow and less snow pack Exacerbate #7, 8, 9, and 12	ISAB (2007); Mote et al. (2014); Williams et al. (2015a)
7. Higher-than-historical average winter flows	Scouring of larval lampreys from their residence sediment burrows and flushing them out of headwater streams and into larger rivers where they may be subject to more predation, and/or into estuaries prior to their physiological readiness to thrive in seawater Exacerbate #8	ISAB (2007); Mote et al. (2014) Sharma et al. (2016); Schaller et al. (2017)
8. Increased flooding	Increased erosion and sedimentation into streams (Exacerbate #20, 23, and 24)	Williams et al. (2015a)
9. Lower-than-historical summer flows	Increased competition for ever lower river flows for use in hydropower, irrigation, and fish and wildlife → exacerbate low flows Slowing/stopping of upstream migration by adults en route to spawning grounds Minimize spawning and rearing habitat Exacerbate $#10, 11, 13, 20, 23, and 24	ISAB (2007); Mote et al. (2014) Clemens et al. (2017) Wade et al. (2013); Clemens et al. (2016); Sharma et al. (2016)
10. Increased competition for ever lower river flows for use in		ISAB (2007); Mote et al. (2014)

	hydropower, irrigation, and fish and wildlife	Exacerbate #9, 11, 13, 20, 23, and 24	
11.	Higher water temperatures in the summer	Increased stream temperatures by 4.3°F by 2050 Restricted habitat Expansion of Smallmouth Bass (known lamprey predators) into more habitats (> 68°F) Increased incidence of developmental abnormalities of larvae; potential changes to rates and incidences of transformation of resident lampreys into adults and anadromous lampreys into juveniles (≥ 68°F) Increased potential for proliferation of pathogens and diseases; expedited sexual maturation or damaging of sexual organs; and slowing/stopping of upstream migration; stress; death Exacerbate #13, 20, 23, and 24	Williams et al. (2015a) ISAB (2007); Williams et al. (2015a) Carey et al. (2011); Lawrence et al. (2014); Williams et al. (2015a) Meeuwig et al. (2005); Schaller et al. (2017); Clemens et al. (2009, 2016, 2017) Clemens et al. (2009; 2016)
12.	Increased flow variability	Scouring of larval lamprey from their residence sediment burrows and flushing them downstream Changes to ecology, including timing and rates of various aspects of river ecology (e.g., insect emergences) Exacerbate #20 (unknown effects on #23 and 24)	Ward et al. (2015) Williams et al. (2015a)
13.	Increase of warmwater areas between coolwater refuges in streams	Habitat fragmentation Exacerbate #20, 23, and 24	Fullerton et al. (2018)
14.	Increased sea surface temperature and temperature stratification by depth	Decreased potential for anadromous lampreys to grow to maximum adult body sizes through negative impacts throughout the food web that affect various prey (exacerbate #21), and through less-than-optimal growth for lampreys Exacerbate #20, and 23	ISAB (2007); Mote et al. (2014); Sharma et al. (2016)
15.	Deoxygenation of some depths in the ocean	Exacerbate #20, 21, and 23	Williams et al. (2015a)
16.	Increased ocean acidification	Exacerbate #21	ISAB (2007); Mote et al. (2014)
17.	Increased sea levels (estuarine/marsh inundation)	?	ISAB (2007); Mote et al. (2014)
18.	Decreased upwelling	Exacerbate #21	ISAB (2007); Sharma et al. (2016)
19.	Delayed upwelling	Mismatch of ocean-entry timing with availability of	ISAB (2007)

during spring	food resources fueled by upwelling Exacerbate #20 and 23	
20. Decrease salmon, steelhead, and trout populations	 Reduce forage prey biomass for anadromous lampreys in the estuary and ocean (exacerbate #23) Increased predation pressure on lampreys (exacerbate #23)	ISAB (2007); Wade et al. (2013); Williams et al. (2015a) Murauskas et al. (2013) Close et al. (2002)
21. Decrease productivity of food webs	(Referring to ocean food webs) Exacerbate #20 and 23	ISAB (2007); Crozier (2016); Sharma et al. (2016)
22. Change distribution of marine prey species for lampreys	Influence #20 and 23 in unknown ways	Pinsky et al. (2013); Cheung et al. (2015)
23. Decrease productivity of anadromous lampreys	Anadromous lampreys = Pacific Lamprey and Western River Lamprey	
24. Decrease productivity of resident lampreys	Resident lampreys = Western Brook Lamprey and Pacific Brook Lamprey	

Table A9.2. Some examples of complex, cumulative, and potentially synergistic effects of climate change. Most of the examples include interaction among effects listed in Table A9.1.

–	Interactive effects of increased wildfires and diseased and dead/dying trees
–	Interactive effects of increased rain with decreased natural vegetation and changes in vegetation types (erosion, shading, water retention)
–	Influences/dynamics of groundwater (hyporheic) inflows relative to moderating warm rivers and relative to contribution to coolwater refuges
–	Biological use of coolwater refuges in streams
–	Complex ecological interactions within the food webs of marine, estuarine, and freshwater ecosystems (e.g., impacts to the behavior, distribution, and abundance of zooplankton, salmon, and predators, which then may directly or indirectly impact lampreys)
–	Behavioral, physiological, and genetic adaptive capacities of lampreys and other organisms
–	Interactions with human population growth, economies, and development

Appendix 10. Supporting information for management strategies

This appendix presents supplemental information for management strategies discussed in Chapter 6. This information includes:

- existing Oregon Administrative Rules pertaining to lamprey management (Table A10.1)
- artificial obstructions that have LPS or fish ladder modifications to provide upstream passage for adult Pacific Lamprey (Table A10.2)
- recommendations for providing upstream passage for lampreys (Table A10.3)
- recommendations for providing downstream passage for lampreys (Table A10.4)
- relationships between existing ODFW conservation plans and lampreys (Table A10.5)
- existing and new recommended harvest regulations for non-native fishes (Table A10.6).

Table A10.1. Existing Oregon Administrative Rules (OARs) pertaining to lampreys and associated management category relative to Table 5.1. Details on OARs can be found here: https://dfw.state.or.us/OARs/oars.asp#Wildlife. PL = Pacific Lamprey; WRL = Western River Lamprey, and WBL = Western Brook Lamprey

OAR	Species	Brief description	Management category
635-004-0225	PL	Unlawful to use lamprey as bait in commercial fishery	Take (harvest)
635-011-0072 [a]	All lampreys	Prohibits use of lampreys as bait	Take (harvest)
635-011-0100 [a]	PL, WRL, WBL	General rule for personal use: take permit required	Take (harvest)
635-017-0080 [b]	PL	Harvest regulations, Willamette Zone (Willamette Falls)	Take (harvest)
635-041-0020	PL	Exceptions to areas closed to subsistence fishing	Take (harvest)
635-043-0130	PL	Grande Ronde Reservation and Trust Lands Wildlife Management: Permitted harvest of up to 100 lamprey	Take (harvest)
635-044-0430	PL, WRL, WBL	Protected wildlife: prohibits unauthorized take, capture, hold, release or possession	Take (harvest; scientific take)
635-100-0040	PL, WRL, WBL	Sensitive Species [c]	Take (harvest, scientific take)
635-412-0005	PL, WRL	Native fish that migrate as part of their life cycle	Habitat access
635-412-0035	PL, WRL	Specifies passage criteria in fishways, including the absence of overhanging surfaces & presence of rounded surface edges; specialized routes for areas where water velocity is > 2 fps	Habitat access
635-500-4080	PL	Managed for wild production in mid-coast small ocean tributary basins	Hatchery fish
635-500-4390	PL	Managed for wild production in Salmon River Basin	Hatchery fish
635-500-4620	PL	Managed for wild production in Siletz River Basin	Hatchery fish
635-500-4910	PL	Managed for wild production in Alsea River Basin	Hatchery fish
635-500-5090	PL	Managed for wild production in Yachats River Basin	Hatchery fish
635-500-5320	PL	Managed for wild production in Siuslaw River Basin	Hatchery fish
635-500-6060	PL	Re-introduction into the Upper Deschutes Basin, including passage of adults above the Pelton-Round Butte dam complex; manage Deschutes River Basin for wild populations	Take (translocation); Habitat access

[a] Described on page 18 of the 2018 Oregon Sport Fishing Regulations; may be superseded by more recent temporary rules.

[b] Described on page 21 of the 2018 Oregon Sport Fishing Regulations; may be superseded by more recent temporary rules.

[c] Sensitive Species List used to assist prioritization of conservation actions. List available: https://www.dfw.state.or.us/wildlife/diversity/species/sensitive_species.asp

Table A10.2. Artificial obstructions with Lamprey Passage Structures (LPS) or fish ladder modifications designed to provide upstream passage for adult Pacific Lamprey. PGE = Portland General Electric; EWEB = Eugene Water and Electric Board; ODOT = Oregon Department of Transportation; CTWSRO = Confederated Tribes of Warm Springs Reservation of Oregon; CTUIR = Confederated Tribes of the Umatilla Indian Reservation; USBR = U. S. Bureau of Reclamation.

Location	Artificial obstructions	River	Population stratum	Year installed	Owner and operator	Notes
Eel Lake	Dam	Eel Creek	Coastal	2018	ODFW	
Winchester	Dam	North Umpqua	Coastal	2012	ODFW [c]	See Figure A6.2
Oregon Hatchery Research Center	Dam	Fall Creek	Coastal	2005	ODFW	Wooden fish ladder steps, cut at 45^{o} angle
Willamette Falls	Falls & dam	Willamette	Lower Columbia	2008 – 11 [b]	PGE	3 LPS & 1 West Side Lamprey Structure
Sandy River Hatchery	Dam	Sandy	Lower Columbia	2013	ODFW	
Walterville Project	Barrier	McKenzie	Willamette	2010	EWB	Tailrace barrier prevents lamprey from entering powerhouse; return channel/fishway allows lamprey to return to the river. This fishway has rounded entrance corners, and rounded step entrances
Fall Creek	Dam	Fall Creek	Willamette	2018	USACE	New fish ladder passes lamprey to a spot where they are collected (trapped) for manual transport above the dam
Threemile Creek	2 culverts	Threemile Creek	Mid Columbia	2011	ODOT	Ramps on 2 different culverts on Hwy 197
Warm Springs National Fish Hatchery	Hatchery	Warm Springs River	Mid Columbia	2017	CTWSRO / USFWS	
Bonneville	Dam	Columbia	Mainstem Columbia [a]	2004 – 18 2007 – 17 2009 – 18	USACE	_Bradford Island ladder_ LPS, wetted climbing wall and 8 minor mods _Washington shore ladder_ LPS and LFS, 10 minor mods; _Cascade Island ladder_ LPS and Six minor mods
The Dalles	Dam	Columbia	Mainstem Columbia [a]	2011 – 18 2010 – 18		_East shore fish ladder_ 6 minor modifications [d]; _North shore fish ladder_ 3 minor modifications [d]
John Day	Dam	Columbia	Mainstem Columbia [a]	2009 – 13 2011 – 14	USACE	_North shore fish ladder_ LPS with trap box, and 9 minor modifications [d]; _South shore fish ladder_ 3 minor modifications [d]
McNary	Dam	Columbia	Mainstem Columbia [a]	2009 – 14	USACE	_South shore fish ladder_ Entrance structure and 8 minor modifications [d]
Dillon	Diversion	Umatilla	Mid Columbia	2010	Private	Removed by ODFW/CTUIR in 2017. Fish ladder was installed through Mitchell Act and LPS was owned by CTUIR
Three Mile	Dam	Umatilla	Mid Columbia	2009	CTUIR	
Maxwell	Diversion	Umatilla	Mid Columbia	2010	USBR	
Feed	Diversion	Umatilla	Mid Columbia	2010	USBR	

[a] Not a population stratum.

[b] The three Lamprey Passage Structures were first installed in 2008. The West side lamprey structure was installed in 2011.

[c] ODFW owns the fish ladder and LPS, but not the dam.

[d] Minor modifications include rounded entrance weirs or wall corners, adjusted picket leads, velocity control structure, minor ramps, attachment surfaces, rest boxes, screening and orifice grating, viewing or monitoring capabilities.

Table A10.3. Recommendations for providing upstream passage for adult anadromous lampreys in relation to pertinent Oregon Administrative Rules (OARs 635-412-0005 and 635-412-0035; Table A10.1). – = no recommendations at this time.

Considerations	Upstream passage	Addressed in OARs?	Recommendations for existing OARs [a]
Life stage	Adults	Yes	–
Species	Pacific Lamprey; Western River Lamprey	Yes	Include Western Brook Lamprey & Pacific Brook Lamprey as "native migratory fish" [b]
Overhanging surfaces	Avoid/remove	Yes	–
90^{o} angles	Avoid/remove (use rounded edges)	Yes	–
Attractant flow	Laminar (non-turbulent)	Not specified	Include specifying language
Attachment surfaces (resting areas)	Provide plenty of options	Not specified	Include specifying language
Water velocity	< 3 fps	Yes	–

[a] Informed by PLTWG (2017).

[b] OAR 635-412-0005 includes Pacific Lamprey and Western River Lamprey, but not resident Western Brook Lamprey and Pacific Brook Lamprey, which are part of a species complex with Western River Lamprey (Appendix 3).

Table A10.4. Considerations for providing downstream passage and screening for lamprey larvae and juveniles at water diversions and hydropower dams in the Federal Columbia River Power System. References: Dauble et al. (2006); Rose et al. (2008); Rose and Mesa (2012); USFWS (2010); Crandall et al. (2015); Moser et al. (2015a); Goodman et al. (2015, 2017). Recommendations for lampreys should be reconciled with juvenile salmonid needs and should not be implemented if found to be detrimental to juvenile salmonids.

Considerations	**Downstream passage**	
	Water diversions	*Hydropower dams*
Life stage	Larvae & juveniles	Larvae & juveniles
Operational goal	Avoid entrainment and/or impingement by providing velocities slow enough for lamprey to swim away, and by providing screen sizes small enough to avoid impingement	Avoid impingement by providing velocities slow enough for lamprey to swim away.
Mesh type	Prioritize use of perforated plate fish screens, or secondarily, interlock or vertical bar fish screens. Prioritize Vertical Traveling Screens. Avoid wire cloth fish screens	?
Mesh size / bar spacing	Use smallest mesh sizes possible, optimally ≤ 0.09" (3/32")[a] for square and ≤ 0.07" for rectangular mesh	Use of 0.09" spacing bar screens correlated with no lampreys becoming permanently impinged.
Screen types	Passive screens may be more "lamprey-friendly" than active screens because the latter may more readily transport larvae over the screen and into secluded habitat where mortality is likely [b]	Traveling bar screens
Sweeping velocities	Provide sweeping velocities that exceed approach velocities.	NA
Approach velocities	Passive screens: < 0.20 fps Active screens: < 0.40 fps	Provide < 1.6 fps.

[a] 3/32 in mesh size is inadequate for excluding small larval lamprey from water diversions (CRITFC 2011). 3/32 in *is* adequate for turbine bypass screens at hydropower dams in the FCRPS, where researchers assessed the swimming abilities and behaviors of much larger larval and juvenile lamprey relative to turbine bypass screen materials.

[b] However, passive screens may be more likely to clog, resulting in reduced screen area and higher approach velocity.

Table A10.5. Oregon Department of Fish and Wildlife conservation and recovery plans that are surmised, in most cases, to be beneficial (directly and indirectly) to lamprey species covered in the CPL. The plans are ordered by publication year. Horizontal arrows (→) should be read as "leads to". PL = Pacific Lamprey; WRL = Western River Lamprey

Plan name	Principal species	Affected population stratum	Management action & potential effect	Citations
Oregon Plan for Salmon and Watersheds	Salmonids	All	A) Through multiple actions, conserve salmonid species and watershed health→More prey resources (salmon) for PL in the ocean; also beneficial to all lampreys	Background and legislation provided in Arha et al. (2003)
Oregon Coast Coho Conservation Plan for the State of Oregon	Coho Salmon	Coastal Rogue/South Coast	A) Through multiple actions, conserve Coho Salmon→More prey resources (Coho Salmon) for PL in the ocean B) Encourage and participate in habitat protection and restoration, with an emphasis on stream complexity (includes implementation of the Oregon Plan); encourage use of beavers to restore habitats→see A; also improves conditions for all life stages of lampreys	ODFW 2007a
Lower Columbia River Conservation and Recovery Plan for Oregon Populations of Salmon and Steelhead	Coho, Chinook, and Chum salmon; steelhead	Lower Columbia	A) Through multiple actions, conserve Coho Salmon, Chinook Salmon, and steelhead→More prey resources (Coho Salmon, Chinook Salmon, and steelhead) for PL in the ocean B) Maintain fish screens→see A; also may reduce larval lamprey entrainment/impingement on screens C) Develop recommendations to address complex, large-scale threats (climate change and development), and how these threats affect river flows and runoff from impervious surfaces→see A; also beneficial to alleviating the limiting factors for lampreys that will be exacerbated by the aforementioned threats D) Conduct analyses on climate change and use the results to prioritize actions to benefit salmonids→see A; also beneficial for lampreys E) Limit surface and groundwater withdrawals in the future→see A; also beneficial for lampreys F) Develop and implement management plans for storm water→see A; also beneficial for lampreys G) Provide education and outreach to resource owners, developers, and contractors→see A; also beneficial to lampreys H) Develop education and outreach on the benefits of beaver dams to ecosystems and fishes; provide landowner assistance with regards to property damage from beavers; provide incentives to landowners managing their land to achieve the habitat benefits that beavers provide I) Include floodplain and channel migration maps into land use planning; develop regulations to minimize impact from development→see A; also beneficial to lampreys J) Reduce pinniped, non-salmonid fish, and bird predation on salmonids→see A; also should reduce overall predation on PL and WRL	ODFW 2010a
Conservation and Recovery Plan for Oregon Steelhead Populations in the Middle Columbia River Steelhead	steelhead	Mid Columbia	A) Through multiple actions, conserve steelhead→More prey resources (steelhead) for PL in the ocean B) Improve FCRPS facilities and operations to increase steelhead survival (adult and juvenile)	ODFW 2010b

Distinct Population Segment			and mainstem Columbia River habitat quantity and quality→Potentially improve lamprey passage; improve habitat for all life stages of lampreys C) Restore habitat in the Columbia River estuary; protect and restore habitats and provide floodplain connectivity in tributaries; remove or replace artificial obstructions and provide passage and provide adequate screening for irrigation diversions; adjust cattle grazing practices near streams; improve Columbia River and tributary conditions (better water quality and more water quantity); implement water conservation measures to keep more water instream →see A; also should improve conditions for all life stages of lampreys D) Reduce pinniped and bird predation on salmonids→see A; also should reduce overall predation on PL and WRL	
Lower Columbia River and Oregon Coast White Sturgeon Conservation Plan	White Sturgeon	Lower Columbia Coastal Rogue/South Coast	A) Through multiple actions, conserve White Sturgeon→more predation on larval and adult PL by White Sturgeon, but less predation on adult PL by pinnipeds (if they instead feed on White Sturgeon) B) Encourage appropriate operation of FCRPS dams to improve habitat quality and quantity, habitat connectivity, and flow and flow variation→see A; also, May have various positive and potentially negative impacts on all life stages of lampreys to unknown extents C) Reduce pinniped predation on White Sturgeon→ see A; also, may lead to less predation on adult PL D) Encourage and participate in habitat protection and restoration in Lower Columbia River, Oregon Coast, and adjacent areas→improved habitat for all life stages of lampreys	ODFW 2011a
Upper Willamette River Conservation and Recovery Plan for Chinook Salmon and Steelhead	Chinook Salmon, steelhead	Willamette	A) Through multiple actions, conserve Chinook Salmon, and steelhead→More prey resources (Chinook Salmon, and steelhead) for PL in the ocean B) Encourage and participate in habitat protection and restoration, including increasing riparian buffers and reducing pollutants (non-point source input and urban and agricultural runoff); designate instream flow targets to increase water quantity; evaluate water withdrawals to attempt to keep more water instream; seek breaching of small artificial obstructions or passage improvements→see A; also improves conditions for all life stages of lampreys C) Provide passage for salmonids at high-head dams→see A D) Reduce pinniped, non-salmonid fish, and bird predation on salmonids→see A; also should reduce overall predation on lampreys	ODFW 2011b
Rogue River Spring Chinook Salmon Conservation Plan Conservation Plan for Fall Chinook Salmon in the Rogue Species Management Unit	Chinook Salmon	Rogue/South Coast	A) Through multiple actions, conserve Chinook Salmon→More prey resources (Chinook Salmon) for PL in the ocean B) Operational changes to Lost Creek, Gold Ray, and Applegate dams, including reservoir levels, timing and extent of discharge; additional water allocations from Big Butte Creek→see A & F; also, more flows and cooler temperatures should generally benefit lampreys (but the timing of these flows relative to the life histories of lampreys in the Rogue is	ODFW 2007b ODFW 2013

			unknown) C) Support removal of artificial obstructions→see A; also, many benefit all life stages of lampreys through improved habitat accessibility and population connectivity D) Support habitat protection and restoration→see A; also may benefit lampreys E) Decrease introductions of non-native species→see A; also would benefit all life stages of lampreys F) Control non-local Umpqua Pikeminnow through encouragement of fishing for them and via cool water releases (see B)→see A; also may benefit lampreys if Umpqua Pikeminnow depredate them	
Coastal Multi-species Conservation and Management Plan	Chinook Salmon, Chum Salmon, steelhead, Cutthroat Trout	Coastal Rogue/South Coast	A) Through multiple actions, conserve Coho Salmon, Chinook Salmon, and steelhead→More prey resources (Coho Salmon, Chinook Salmon, and steelhead) for PL in the ocean B) Use prioritization process, maps, and prioritization tool for identifying key river and estuary habitats needing protection and restoration; encourage, coordinate, and advise partners on protection and restoration of these key habitats; remove artificial obstructions; encourage use of beavers to restore habitats→see A; also should improve conditions for all life stages of lampreys C) Haze pinniped and bird predators on salmonids; remove newly introduced, non-native fishes; control introduction of non-native fishes to flowing waters; continue removal of harvest limits for bass in the Umpqua River→see A; also should improve conditions for all life stages of lampreys	ODFW 2014

Table A10.6. Existing harvest regulations and recommended changes for non-native fishes, by zone. The recommended changes apply to rivers and streams (unless noted otherwise).

Zone regulations	Species	Existing bag & size limits?	Recommended regulation changes
Northwest Zone	Bass	Yes	*Remove all bag / size limits*
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
	Striped Bass	No	–
Southwest Zone	Bass	Yes (exceptions)[a]	*Remove all bag / size limits*
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
	Striped Bass	No	–
Willamette Zone	Bass	Yes (exceptions)[b]	*Remove all bag / size limits*[c]
	Common Carp	No	–
	Catfish	No	*Remove all bag / size limits*
	Walleye	Yes	*Remove all bag / size limits*
	Striped Bass	No	–
Central Zone	Bass	Yes (exceptions)[d]	*Remove all bag / size limits*
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
Northeast Zone	Bass	Yes (exceptions)[e]	*Remove all bag / size limits*
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
Southeast Zone	Bass	Yes (exceptions)[f]	*Remove all bag / size limits*
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
Snake River Zone	Bass	Yes[g]	*Remove all bag / size limits*
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
Columbia River Zone	Bass	No	–
	Common Carp	No	–
	Catfish	No	–
	Walleye	No	–
	Striped Bass	No	–

[a] No bag or size limits in portions of the Coquille, , Smith, and Umpqua rivers and Cow Creek.

[b] No bag or size limits in the mainstem Willamette River above Albany, and in the Molalla, Santiam and Calapooia basins.

[c] Recommended changes apply to flowing streams, and in addition, to Lookout Point Reservoir.

[d] No bag or size limits in portions of the mainstem Deschutes River; Lake Billy Chinook, Laurance Lake, and Suttle Lake.

[e] No bag or size limits in the John Day or Grande Ronde River.

[f] No bag or size limits in the southwest corner of the zone.

[g] No bag or size limits from state line to Hells Canyon Dam.

Appendix 11. Anticipated near term implementation

This appendix provides details on management strategies and RME that are anticipated to be accomplished in the near term (i.e., next five years).

MANAGEMENT STRATEGIES

Education and outreach

- Update all lamprey-related ODFW web pages.
- Identify opportunities for collaboration with other entities.
- Design and create high-quality, information brochures or pamphlets on the biology of lampreys for dissemination at ODFW offices.
- Acquire funding to design and create high-quality information signage for Lamprey Passage Structures owned by ODFW and potentially for those owned by interested partners (Table A10.2).
- Assist in teaching lamprey short courses and lamprey-specific seminars through River Restoration North West (RRNW)[27] and Portland State University (PSU)[28].
- Give oral presentations and seminars at various venues.
- Work with partners to provide larval lamprey identification workshops[29].
- Continue to work with and provide information and guidance to ODFW field staff to implement management and RME actions.

[27] *ODFW participated in a symposium on lampreys at RRNW in 2019, and will be assisting on teaching a short education course on lampreys at RRNW in 2020.*

[28] *ODFW assisted teaching a short course on "Lamprey Ecology and Management" for PSU's Environmental Professionals Program in 2019, and anticipates doing so again when the course is offered in 2021.*

[29] *ODFW and partners provided a larval lamprey identification workshop at The Dalles in 2018. ODFW and partners are currently planning another larval lamprey identification workshop.*

Provide passage and screening

- Continue to provide information on lamprey passage and screening requirements and unknowns to ODFW staff and to review passage design criteria for ODFW facility updates.
- Update passage OARs per Table A10.3.
- Coordinate priorities with results from RME (see "Prioritize passage and screening", below).

Protect and restore habitat

- Continue existing tactics (see Chapter 6) for habitat protection and restoration.

Water conservation

- Identify areas where lampreys are distributed but do not currently have instream flow protections, measure instream flows where necessary, and identify specific instream flow protections for lampreys.

Translocation

- Identify potential areas where translocation of Pacific Lamprey could occur, based on where ecological, social, partnerships, and logistical considerations align.
- See "Near term RME: Assess translocation", below.

Establish in-water work BMPs

- Continue to work with the Lamprey Technical Workgroup to update existing BMPs.

Implement angling regulations on non-native fishes

- Continue existing strategies to contain and control new, non-sanctioned introductions of non-native fishes.
- Continue to prohibit introductions of non-native fishes into flowing waters.

- Implement modified angling regulations that remove bag and size limits on non-native fishes in flowing waters (Table A10.6).

Pinniped management

- Continue implementation of pinniped management.

RME

Improve distribution information

- Identify the many recent, current, and ongoing lamprey surveys being done by different entities, and identify opportunities for use of this data by ODFW for species distribution modeling.
- Compare survey methods for lampreys and provide recommendations for standard protocols for future surveys.
- Conduct surveys on all lamprey species, especially on Western River Lamprey, Western Brook Lamprey, and Pacific Brook Lamprey.

Prioritize passage and screening

- Develop a procedure to prioritize passage and screening at particular artificial obstructions.
- Seek funding for passage and screening fixes.
- See “Inform passage and screening requirements”.

Inform passage and screening requirements

- Identify opportunities to focus on passage studies for lampreys.

Improve knowledge on biology

- Identify opportunities to conduct laboratory and field studies on lampreys.

Estimate take

- Continue existing strategies for estimating scientific take and harvest.

Assess complex, large-scale threats

- Continue to use, adapt, and refine models (e.g., hydrological, climate, and species distribution) to predict future effects of complex, large-scale threats to lamprey status and to limiting factors on these fishes.
- Continue to collaborate with and support partners in information sharing and research.

Assess translocation

- Progress will be contingent upon implementation of the translocation management strategy.

Estimate adult abundance

- Examine the logistical needs (personnel, technology and strategies[30]) and funding needs for counting adult Pacific Lamprey passing Willamette Falls.
- Conduct further analyses on the abundance trend data presented in Appendix 6.

Monitor diversity

- This will be done in the near term, as and if opportunities (partnerships and funding) arise.

[30] *A great deal of knowledge has been gained in advancing the science of counting lampreys at dams on the mainstem Columbia River. It is anticipated that this knowledge can be used to help determine methods for counting adult Pacific Lamprey at Willamette Falls.*