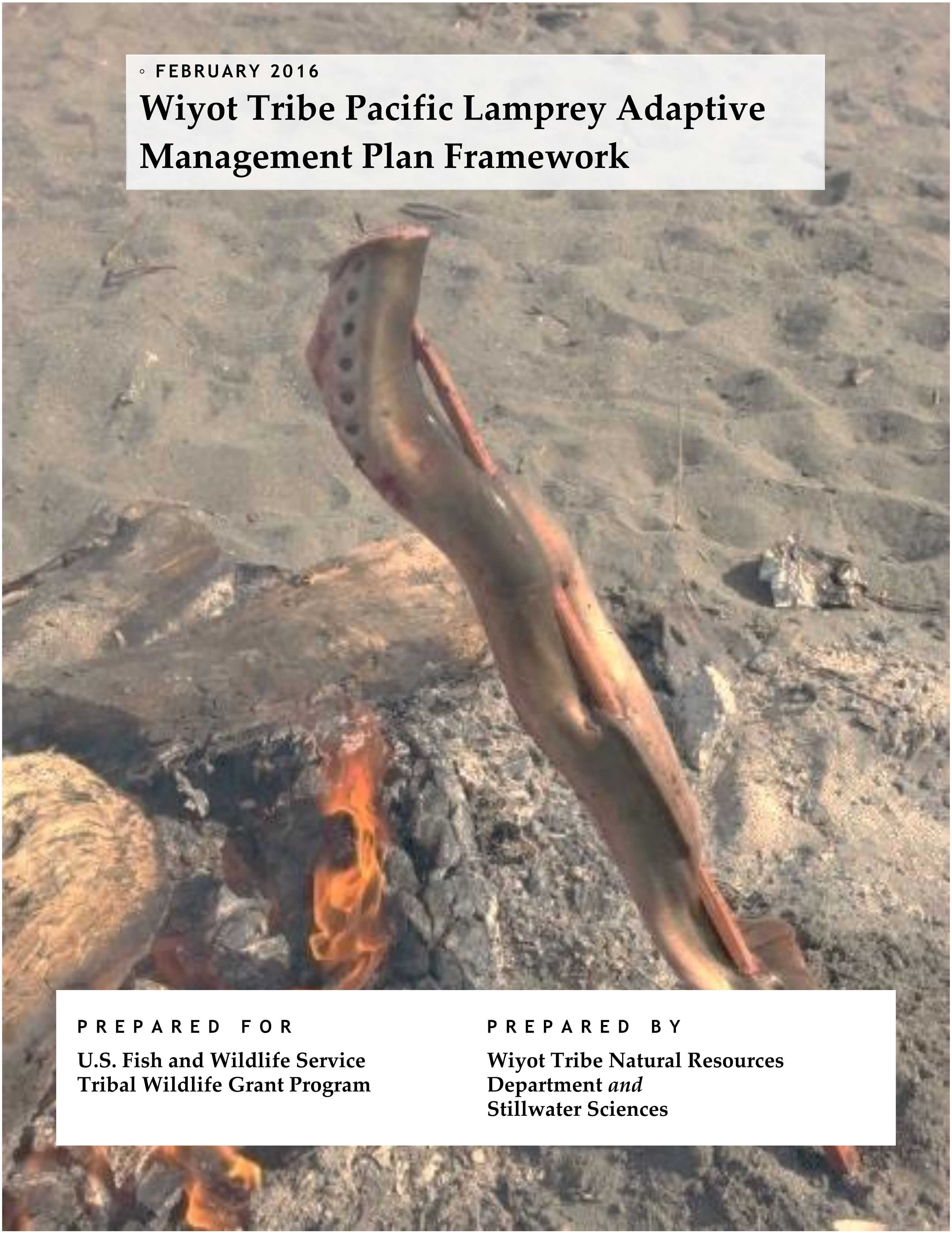
◦ FEBRUARY 2016

Wiyot Tribe Pacific Lamprey Adaptive Management Plan Framework



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Cover photo: Gou'daw (Pacific lamprey) prepared in traditional Wiyot manner on redwood stake (photo by Vincent DiMarzo)

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1 INTRODUCTION

1.1 Background

The Wiyot Tribe shares its name with its ancestral river, *Wiya't*, which translates as "abundance." A significant aspect of that abundance was the *gou'daw*, Pacific lamprey (*Entosphenus tridentatus)*—commonly called "eels," which inspired the river's English name, Eel River. The Eel River watershed is the third largest in California and was once home to abundant runs of salmon, steelhead, sturgeon, and Pacific lamprey. Numerous impacts including water diversions, invasive predators, logging, and sedimentation, have led to significant ecological and habitat degradation and diminished native fish populations that are important to the Wiyot Tribe. The Tribe is renewing its traditional role as active stewards of the natural resources in its ancestral territory, and in recent years has been a driving force for activities aimed at restoring Pacific lamprey and other native fishes.

While the lamprey is and has been an important food source for the Wiyot people, they have also always recognized that the species fulfills a key role in the health of the ecosystem. This understanding has maintained the lamprey as a central aspect of Wiyot culture. Substantial decline of Pacific lamprey populations from historical levels has degraded the ecological balance of the river and threatened to sever the bond between Wiyot people and lamprey. The Pacific lamprey is regarded as an important indicator of ecosystem health not just by the Native American Tribes that depend on them, but by biologists as well (Close et al. 2002, Luzier et al. 2011). In addition to the near disappearance of an extremely important food source, the decline of Pacific lamprey has likely led to disruption of natural predator-prey dynamics and imbalances of nutrient cycles and other ecosystem functions. For the same reasons adult Pacific lampreys are desirable as a human food source, they are also sought after by many aquatic and terrestrial animals: they are not strong swimmers and thus relatively easy to capture and have a very high caloric content – two to five times higher per unit weight than Chinook salmon (Stewart et al. 1983, Whyte et al. 1993). Adult lampreys are preyed upon by numerous fish, birds, and aquatic mammals. Seals, sea lions, ospreys, blue herons, river otters, and bald eagles have all been observed feeding on adult Pacific lampreys in the Eel River and Humboldt Bay (Stillwater Sciences 2010). Like salmon, migrating Pacific lampreys are a critical source of marine-derived nutrients that act to increase the productivity of otherwise nutrient poor stream ecosystems. While in their ammocoete stage, Pacific lamprey are thought to improve overall water quality by acting as filter feeders, and may constitute the highest amount of benthic biomass in some areas (Kan 1975, Close et al. 2002,).

The imperiled condition of the Pacific lamprey is gaining wider recognition. As stated in the United States Fish and Wildlife Service's (USFWS) *Best Management Practices to Minimize Impacts to Pacific Lamprey*, "the Pacific lamprey is included as a state sensitive species in Oregon and Washington, state-listed endangered species in Idaho, designated Tribal trust species, and a 'species of special concern' for the USFWS (USFWS 2010). The Pacific lamprey has been designated as a Forest Service Sensitive Species in Regions 1 and 4, and is classified as a Type 2 species (Rangewide/Globally imperiled) by the Bureau of Land Management." The USFWS's Pacific Lamprey Conservation Initiative (PLCI) has also finalized a *Conservation Agreement for Pacific Lamprey,* signed by federal and state agencies and Northwest Tribes, including the Wiyot Tribe.

In response to the decline of the Pacific lamprey in the region and within their ancestral lands, the Wiyot Tribe has begun implementing a research and monitoring program to guide conservation and restoration of this important species in the Eel River and other streams in their Ancestral Territory. Recent work spearheaded by the tribe includes an information review of Pacific Lamprey in the Eel River Basin (Stillwater Sciences 2010), an evaluation of barriers to Pacific lamprey migration in the basin (Stillwater Sciences 2014a), a conceptual framework for identifying factors limiting lamprey production in the basin (Stillwater Sciences 2014b), a plan to monitor Pacific lamprey in the Eel River basin (Stillwater Sciences and WNRD 2016), an information review of Pacific lamprey in Humboldt Bay tributaries (Stillwater Sciences 2016), and studies of life History of adult Pacific lamprey in Freshwater Creek (Stillwater Sciences et al. 2016). A critical goal of this ongoing research and monitoring program is to improve the ability of the Wiyot Tribe and their co-managers to effectively manage lampreys in the region. Herein, we present an initial framework for achieving this goal: a management plan framework that builds on and incorporates information from the Tribe's recent work, organizing available information and management objectives into a single guiding document. By presenting existing and new data in the framework of a management plan, we will considerably increase the ability for organized and effective management of this species of great Tribal significance. Purpose and overview of plan

The purpose of this plan is to improve the ability of the Wiyot Tribe to effectively manage Pacific lamprey populations in the lower Eel River basin and other portions of Wiyot Ancestral Territory. Ultimately, this plan will serve as a guiding document for achieving the management and population goals set forth below. This plan synthesizes knowledge on Pacific lamprey biology, population status, habitat needs, limiting factors and threats, critical data gaps, and existing management measures. This information will ultimately be used to develop and prioritize conservation and management measures and present adaptive management process for their implementation.

Importantly, development of a species management plan is an iterative process and we understand that we are early in this process—mainly due to the limited amount of information on Pacific lamprey in the region. We envision that this version of the plan will be the first of several iterations and will require additional funding to refine, expand, and implement. Nonetheless, striving for a systematic management framework early in this process will allow the Wiyot Tribe and its co-managers to achieve more holistic and effectual management actions for this species of great Tribal significance.

1.2 Management and Population Goals

The overarching management goal of the Wiyot Tribe is to ensure self-sustaining Pacific lamprey populations that are large enough to fulfill the historical ecological functions of the species and also allow ample subsistence harvest by the Tribe.

Currently, as presented in Section 3, there are insufficient data to estimate the size of the current Pacific lamprey population or to understand whether it is large enough to achieve ecological function. While tribal harvest still occurs, in many years it appears to be greatly limited by availability of lamprey to harvest and available evidence suggests the population has declined substantially from historical levels. After additional years of population monitoring is conducted and our understanding of population size and dynamics is improved, we will begin to set more specific population goals in future iterations of this plan.

1.3 Geographical reach of plan

The geographical focus of this plan includes all watersheds within the Wiyot Ancestral Territory. This area includes the Eel River, Humboldt Bay tributaries, and the Mad River (Figure 1). A secondary focus will be areas upstream that have impacts on lamprey and their habitats in Wiyot Ancestral Territory.

This version of the plan focuses heavily on the Eel River and secondarily on Humboldt Bay Tributaries where more information is available. To our knowledge, at this time very little data on the species exists for the Mad River and there has been no effort to compile and synthesize existing information on population status, distribution, or basic biology and life history there. The Mad River is within Wiyot Ancestral Territory and of interest to the Tribe, and is therefore considered in this plan. Ultimately, however, we foresee that research, monitoring, and management of lamprey in the Mad River by the Wiyot Tribe will be coordinated closely with other entities, including Blue Lake Rancheria.

While this plan focuses on management of lampreys in streams within Wiyot Ancestral Territory, we want to emphasize the importance of understanding how larger-scale processes and management decisions affect populations there. As described in Section 2 below, Pacific lampreys are thought to show weak to no fidelity to natal streams (homing). For this reason, lamprey production from adjacent watersheds is likely important in contributing to population size in the Eel River and Humboldt Bay region. Therefore, species management in close coordination with regional partners, including USFWS (through the ongoing PLCI) and other Tribes is critical.

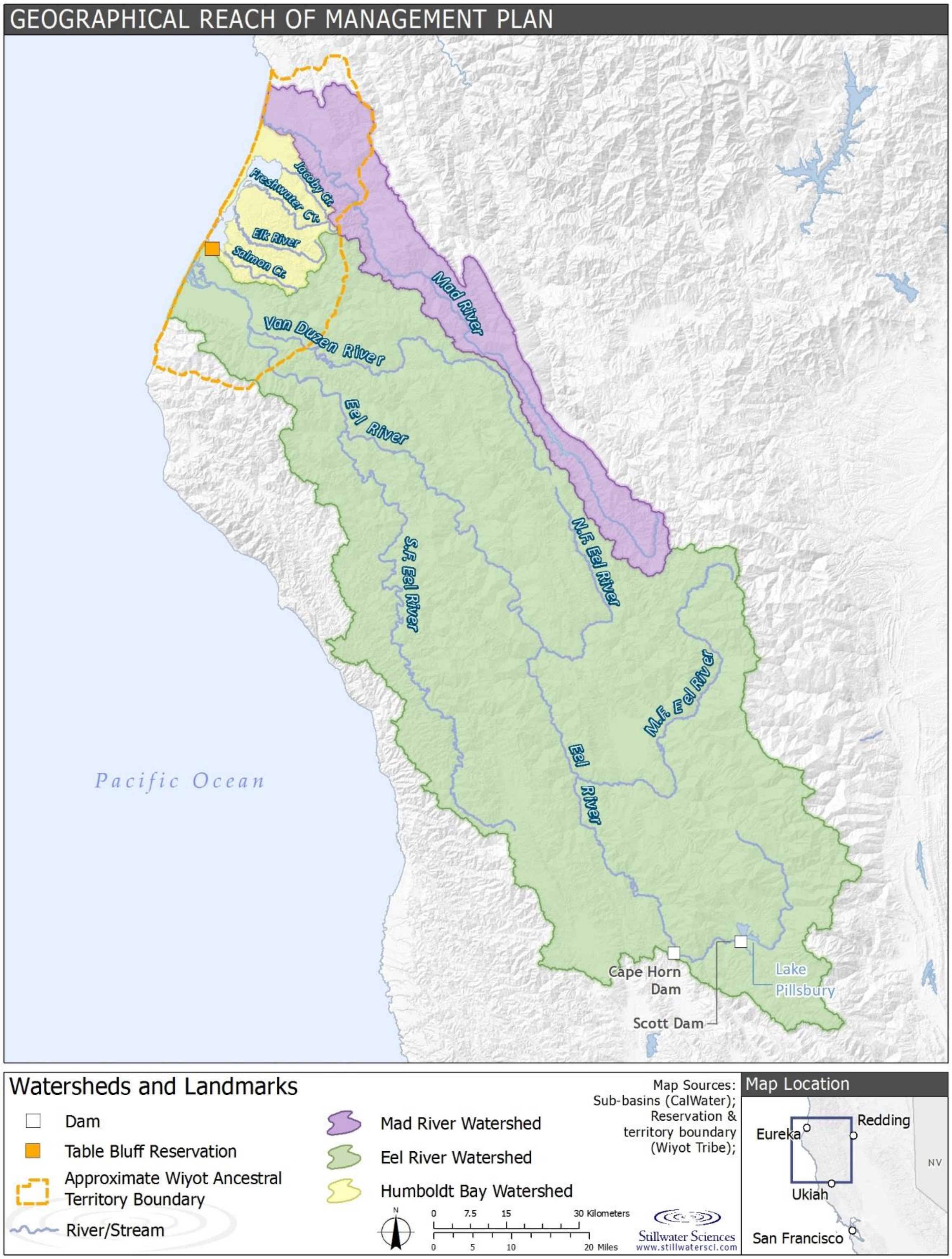

Figure 1 Geographical reach of the Wiyot Tribe Pacific Lamprey Adaptive Management Plan.

2 POPULATION STRUCTURE AND GENETICS

Unlike Pacific salmon and steelhead, Pacific lampreys do not necessarily home to natal spawning streams (Moyle et al. 2009, Spice et al. 2012). Instead, migrating adults appear to select spawning streams, at least in part, based on bile acid compounds secreted by ammocoetes that act as migratory pheromones (Robinson et al. 2009, Yun 2011). This mode of selecting spawning streams induces migratory adults to select locations where ammocoete rearing has been successful due to suitable habitat, and therefore has been called the "suitable river strategy" (Waldman et al. 2008). Notably, Fine et al. (2004) found evidence that different lamprey species within the family Petromyzontidae employ a common migratory pheromone and adults of one species are attracted to bile acid compounds released by other species. Therefore, it is likely that Pacific lampreys can select new habitat due to attraction to pheromones released by resident brook lampreys.

Lack of homing suggests that extensive gene-flow occurs between watersheds and regions, and thus Pacific lamprey populations are not expected to exhibit the fine scale stock-structure seen in migratory salmonids. Results of recent genetics studies generally support this assertion. In a study of Pacific lamprey population structure using mitochondrial DNA markers, Goodman et al. (2008) found little genetic differences among individuals sampled at widely dispersed sites across the species' range, indicating substantial genetic exchange among populations from different streams. Results of a study that applied amplified fragment length polymorphisms (AFLPs) to assess genetic population structure of Pacific lamprey also indicated considerable historical gene flow across the range of the species, but found significant genetic divergence among samples collected in the Pacific Northwest, Alaska, and Japan, suggesting some regional-scale genetic structure (Lin et al. 2008). Results also indicated a weak trend of decreasing gene flow with increased geographical distance, suggesting a pattern of genetic isolation by distance. Lin et al. (2008) also found significant genetic differences among fish from different locations within the Pacific Northwest, but these differences did not follow an obvious geographical pattern. Recent analyses of microsatellite and mitochondrial DNA from Pacific lampreys collected from 20 sites in British Columbia, Washington, Oregon, and California also indicated low but significant genetic differentiation among sites and weak but significant genetic isolation by coastal distance, based on analysis of the influence of distance between estuaries (i.e., marine dispersal distance between watersheds) on genetic variation (Spice et. al 2012). This study supports the premise that Pacific lampreys do not home to their natal streams, but indicates that relatively limited dispersal at sea may contribute to the weak, larger-scale genetic structure observed. These findings appear to be consistent with a parasitic feeding mode and relatively poor swimming performance (i.e., some fraction are carried away a long distance by migratory hosts, while some fraction likely remain relatively close, returning to their natal watershed or adjacent basins).

Despite the generally weak fine-scale population genetic structure and lack of homing indicated by these studies, there is some evidence for significant adaptive genetic divergence related to migration timing and body size among some Pacific lamprey collections, which suggests natural selection is acting on migrating adult lampreys (Hess et al. 2013).

Results of the studies summarized above help illustrate the evolutionary context of lamprey population dynamics and reveal some important principles for identifying key limiting factors in managing and restoring populations—most notably the need to develop regionally coordinated management, restoration, and monitoring strategies.

3 POPULATION STATUS AND DISTRIBUTION

3.1 Eel River

3.1.1 Status

Very few data are available on historical or current Pacific lamprey abundance in the Eel River basin because, until recently, the population has never been systematically monitored. However, there are widespread and consistent reports of a considerable decline in abundance of migrating and spawning adults and carcasses in the basin. Interviews with biologists, Wiyot Tribal eelers and elders, and other stakeholders living or working in the basin all indicate a decline in the Eel River Pacific lamprey beginning around the 1950s. Observations of migrating adults at Cape Horn Dam also point toward a significant decline since the late 1980s when hundreds of adults were commonly observed in the fish ladder and on the dam (A. Grass, CDFG, pers. comm.).

The root causes of lamprey population decline are unknown, but are in all likelihood, multifaceted. Due to similarity in habitat requirements and life histories between the Pacific lamprey and anadromous salmonids, as well as some parallels in the timing of their population collapse (i.e., following the 1955 and 1964 floods), it is likely that many of the same factors led to their decline. Dams, diversions, grazing, urban development, mining, estuary modification, decline in prey abundance, and non-native species have all been postulated as factors limiting Pacific lamprey abundance across their range (Nawa 2003, Moyle et al. 2009). Little direct evidence of specific factors limiting abundance in the Eel River basin exists. However, likely factors include the Potter Valley Project dams and water withdrawals, migration obstructions affecting upstream passage to historical spawning areas, the effects of the large floods of 1955 and 1964, forest management and roads, and non-native species—as well as cumulative and synergistic impacts from these factors.

Data from monitoring conducted to-date, as well as future long-term monitoring of the species in the Eel River will be used to evaluate status and describe distribution. The methods and process described in the Long-term monitoring plan will be followed.

3.1.2 Distribution

Available data indicates that Pacific lampreys are relatively widespread in the Eel River basin, from the lower mainstem Eel to relatively small headwater tributaries (Stillwater Sciences 2010, Stillwater Sciences 2014a, Stillwater Sciences and WNRD 2016). Pacific lamprey spawning has been observed in a wide range of stream sizes, but is more prevalent in higher order streams (active channel widths >15 m [49 ft]) than smaller, low-order streams (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009). The species is expected to spawn in accessible stream reaches throughout much of the Eel River basin and have been documented spawning in channels draining areas ranging in size from approximately 6 km^2 (e.g., Ryan Creek) >9,000 km^2 (lower mainstem Eel River (Stillwater Sciences 2010; Stillwater Sciences and WNRD 2016). Similarly, newly-emerged and young-of-the year ammocoetes are expected to be widely distributed throughout the Eel River basin, occurring from spawning locations downstream considerable distances to rearing locations as far downstream as the mainstem Eel River near Fernbridge. Known distribution of each life stage is discussed in detail in Section 4 below.

3.2 Humboldt Bay Tributaries

3.2.1 Status

A recent review of available information on Pacific lamprey in Humboldt Bay, or *Wigi*, tributaries indicates that there are very few data to assess historical population levels of Pacific lamprey in Humboldt Bay tributaries (Stillwater Sciences 2016). Furthermore, with the exception of Freshwater Creek, where focused studies are being conducted and more extensive data are available, the review demonstrated that, overall, very little data are available to assess current population status in the Humboldt Bay watershed.

Captures of adult Pacific lampreys by the California Department of Fish and Wildlife (CDFW) at a weir in lower Freshwater Creek from 2007–2015 do not indicate any obvious upward or downward trends in relative abundance during the period (Stillwater Sciences et al. 2016). Redd counts from annual spawning surveys conducted by CDFW over approximately 8 km (5 mi) of mainstem Freshwater Creek from 2011–2015 also do not indicate any trends in relative abundance of the species over time (Stillwater Sciences et al. 2016). Similarly, there was no apparent trend in the numbers of adult lampreys collected by Green Diamond Resource Company using an outmigrant trap in lower Ryan Creek (a major tributary to Freshwater Slough) from 2004–2014 (Stillwater Sciences 2016).

As additional years of data are collected from these efforts in Freshwater Creek, trends in the Pacific lamprey population can be further evaluated.

3.2.2 Distribution

The recent review by Stillwater Sciences (2016) indicates that the Pacific lamprey is widely distributed within the Humboldt Bay watershed. The review documented presence of Pacific lamprey in each major tributary, widespread distribution within Freshwater Creek and in several of its tributaries, and evidence of spawning in relatively small streams such as Jolly Giant Creek and Graham Gulch (drainage areas of 4.2 km^2 and 6.5 km^2, respectively). Notably, the review also indicated ammocoetes of unknown species were documented throughout the watershed—including both small headwater streams and tidally influenced reaches near Humboldt Bay. However, very little information was available to inform upper distribution or species presence within many stream reaches in the study area and focused lamprey species distribution surveys are a critical need through the Humboldt Bay watershed for effective species management.

3.3 Mad River

The Mad River, or *Baduwa't*, is within Wiyot Ancestral Territory and of interest to the Tribe and is therefore considered in this species management plan. However, we recommend coordinating closely with Blue Lake Rancheria to monitor the species as the population status in the Mad River remains a large data gap. No concerted effort has been made to compile and synthesize existing information on population status, distribution, or basic biology and life history (including tribal knowledge, incidental capture by other studies, anecdotal observations from biologists and others working and living in the watershed).

4 LIFE HISTORY, HABITAT REQUIREMENTS, AND THREATS

4.1 Life History Overview

This section provides an overview of Pacific lamprey life history and population structure. Section 4.2 provides more detailed information on timing, spatial distribution, movement, habitat requirements, and factors potentially affecting survival of each life stage in the Eel River.

The Pacific lamprey is a large, widely distributed anadromous species that rears in fresh water before outmigrating to the ocean, where it grows to full size (approximately 400–700 mm [16–28 in]) prior to returning to freshwater streams to spawn and ultimately die. The species is distributed across the northern margin of the Pacific Ocean, from central Baja California north along the west coast of North America to the Bering Sea in Alaska and off the coast of Japan (Ruiz-Campos and Gonzales-Guzman 1996, Lin et al. 2008). Adults migrate into and spawn in a wide range of river systems, from short coastal streams to tributaries of the Snake River in Idaho, where individuals may migrate over 1,450 km (900 mi) (Claire 2004). Within the Eel River basin, Pacific lampreys are widely distributed. They are found in all major sub-basins and in relatively small and large streams (Stillwater Sciences 2010, Stillwater Sciences 2014a, Stillwater Sciences and WNRD 2016).

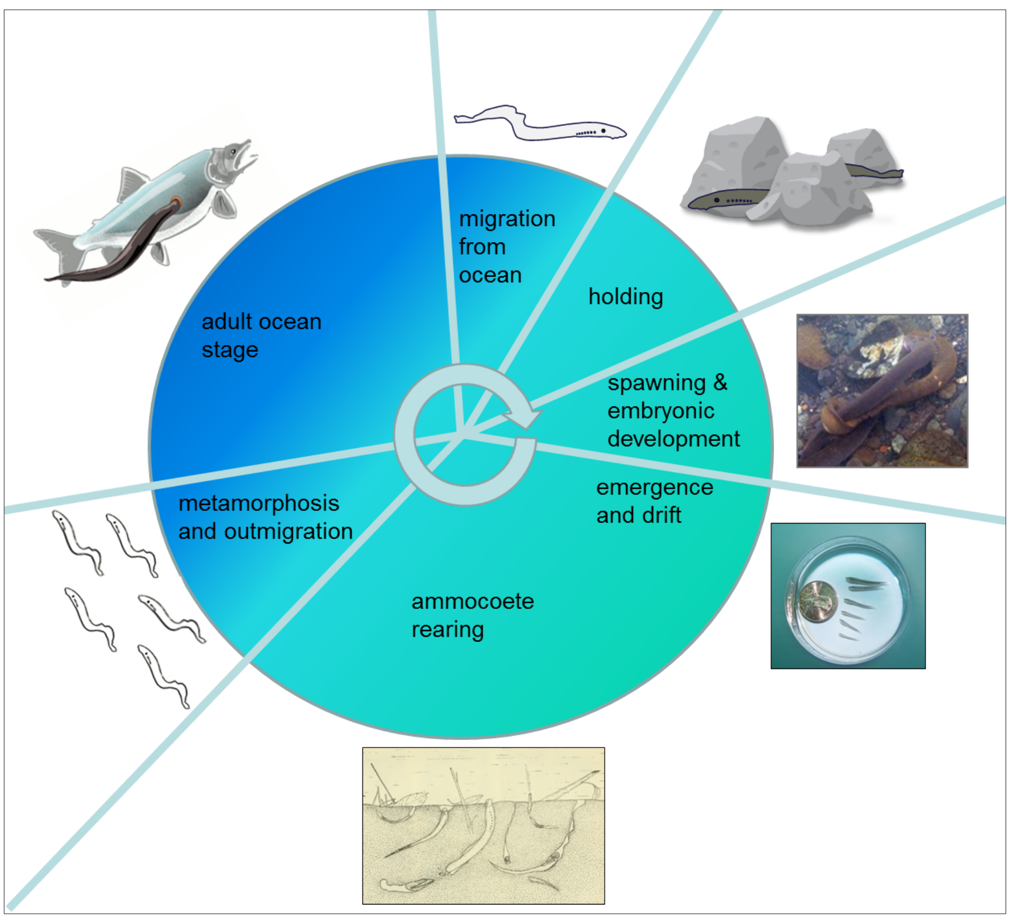

Figure 2: Pacific lamprey life cycle.

Pacific lampreys typically spawn from March through July depending on water temperatures and local conditions such as seasonal flow regimes (Kan 1975, Brumo et al. 2009, Gunckel et al. 2009). More inland, high-elevation, and northerly populations generally initiate spawning considerably later than southerly populations (Kan 1975, Beamish 1980, Farlinger and Beamish 1984, Chase 2001, Brumo et al. 2009), presumably due to cooler water temperatures. Spawning generally takes place at daily mean water temperatures from 10–18°C (50–64°F), with peak spawning around 14–15°C (57–59°F) (Stone 2006, Brumo 2006). Redds are typically constructed by both males and females in gravel and cobble substrates within pool and run tailouts and low gradient riffles (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009). During spawning, eggs are deposited into the redd and hatch after approximately 15 days, depending on water temperatures (Meeuwig et al. 2005, Brumo 2006). Pacific lampreys are highly fecund: depending on their size, females lay between 30,000 and 240,000 eggs (Kan 1975). In comparison, Chinook salmon generally lay approximately 4,000 to 12,000 eggs (e.g., Jasper and Evensen 2006). Pacific lampreys typically die within a few days to two weeks after spawning (Pletcher 1963, Kan 1975, Brumo 2006). The egg-sac larval stage, known as prolarvae, spend another 15 days in the redd gravels, during which time they absorb the remaining egg sac, until they emerge at night and drift downstream (Brumo 2006).

After drifting downstream, the eyeless larvae, known as ammocoetes, settle out of the water column and burrow into fine silt and sand substrates that often contain organic matter (Figure 2). Within the stream network they are generally found in low-velocity, depositional areas such as pools, alcoves, and side channels (Torgensen and Close 2004). Depending on factors influencing growth rates, they rear in these habitats from 4 to 10 years, filter-feeding on algae and detrital matter prior to metamorphosing into the adult form (Pletcher 1963, Moore and Mallatt 1980, van de Wetering 1998). During metamorphosis, Pacific lampreys develop eyes, a suctoral disc, sharp teeth, and more-defined fins (McGree et al. 2008). After metamorphosis, smolt-like individuals known as macropthalmia migrate to the ocean—typically in conjunction with high-flow events between fall and spring (van de Wetering 1998, Goodman et al. 2015).

In the ocean, Pacific lampreys feed parasitically on a variety of marine fishes (Richards and Beamish 1981, Beamish and Levings 1991, Murauskas et al. 2013). They are thought to remain in the ocean for approximately 18–40 months before returning to fresh water as sexually immature adults, typically from winter to early summer (Kan 1975, Beamish 1980, Starcevich et al. 2014, Stillwater Sciences et al. 2016). In the Klamath and Columbia rivers, they have been reported to enter fresh water year-round (Kan 1975, Larson and Belchik 1998, Petersen Lewis 2009). Notably, recent research suggests that two distinct life history strategies, analogous to summer and winter steelhead, may occur in some river systems: one, an "ocean maturing" life history that likely spawns several weeks after entering fresh water, and two, a "stream-maturing" life history—the more commonly recognized life history strategy of spending one year in fresh water prior to spawning (Clemens et al. 2013). The adult freshwater residence period for the stream-maturing life history can be divided into three distinct stages: (1) initial migration from the ocean to holding areas, (2) pre-spawning holding, and (3) secondary migration to spawning sites (Robinson and Bayer 2005, Clemens et al. 2010, Starcevich et al. 2014). Seasonal timing for each of these life stages in the Eel River basin is detailed in Section 2.3.

4.2 Species Account for Pacific Lamprey in the Eel River

This section describes what is known about timing, spatial distribution, movement, habitat requirements, and factors potentially affecting survival of each life stage in the Eel River.

Where information specific to the Eel River are not available, studies conducted in other river systems are cited, with the assumption that many key life history characteristics and factors affecting survival are similar across the species' range.

This summary only describes the stream-maturing life history, which appears to be most common and for which most information is available (Clemens et al. 2013). The prevalence of the ocean-maturing life history in the Eel River basin and potential differences in timing, distribution, and movement patterns between the two life histories are unknown.

4.2.1 Initial adult upstream migration

4.2.1.1 Life history and distribution

Interviews with Wiyot Tribal eelers indicate that, based on harvest at the mouth of the Eel River, adult Pacific lampreys typically enter the lower river from the ocean in catchable numbers between January and at least June (Stillwater Sciences 2010, Table 1). Creel surveys conducted at the Eel River mouth in 2014 indicated peak harvest, and presumably migration, occurred in late-February (Stillwater Sciences and WNRD 2016). Historically, eelers continued to capture adult lampreys further upstream in the mainstem Eel and South Fork Eel rivers later in the summer as the run season progressed (e.g., July at Benbow Dam on the South Fork Eel), indicating that upstream movement likely continues through the summer. In the nearby Klamath River, entry into fresh water generally begins in January and ends by June; although there is some evidence that individuals may enter the river as early as November (Petersen-Lewis 2009, McCovey 2011). In fact, recent accounts from the lower Klamath River indicate the presence of migratory adult lampreys during the summer and early fall (D. Goodman, USFWS, pers. comm., 28 September 2015), and such alternative migratory strategies may also exist in the Eel River.

In some river systems where migrating Pacific lampreys have been tagged and tracked, most upstream movement associated with the initial migration ceases by mid-July when flows approach summer lows and water temperatures begin to peak (Clemens et al. 2012, McCovey 2011, Starcevich et al. 2014); although considerable movement occurs into early fall in other river systems (Robinson and Bayer 2005, Fox et al. 2010, Lampman 2011). Multiple years of counts of adult Pacific lampreys at Columbia River dams showed that migration occurred earlier in the spring and summer during warm years with lower flows and later during cool years with higher flows (Keefer et al. 2009). Fox et al. (2010) found that most movement occurred at night, based on detections at fixed site radio antennas, suggesting that lampreys likely cease migrating during the day.

In nearby Freshwater Creek, timing of capture of immature adult Pacific lamprey at a weir near the head of tide is presumably indicative of timing of adult entry into fresh water. From 2012–2015, Pacific lampreys categorized as immature have been captured at the weir from as early as late-December through June, with peak capture of immature lampreys generally occurring from March through May (Stillwater Sciences et al. 2016)..

Adults migrating from the ocean to holding areas are presumably distributed throughout much of the Eel River basin, from the estuary to the locations where they hold through the summer and winter prior to spawning. Documented holding areas include upper reaches of the mainstem as well as medium to small tributaries in the South Fork sub-basin (Stillwater Sciences 2014b).

Table 1: Approximate timing for freshwater life stages of stream-maturing adult Pacific lampreys of a single run cohort.

Adult freshwater stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Initial migration from ocean[1,2,3,4]	■	■	■	■	■	■	■	■											
Pre-spawning holding[2,3,5]						■	■	■	■	■	■	■	■	■	■	■			
Secondary migration to spawn and spawning[1,3,6,7]															■	■	■	■	■

1 Stillwater Sciences (2010)
2 McCovey (2011)
3 Starcevich et al. (2013)
4 Some individuals may enter fresh water as early as November. In the Klamath River, this early run was historically more common (Petersen-Lewis 2009, Larson and Belchik 1998).
5 Some individuals make upstream movements during winter following high-flow events (McCovey 2011, Lampman 2011, Starcevich et al. 2014).
6 Robinson and Bayer (2005)
7 Lampman (2011)

4.2.1.2 Habitat requirements

Little is known about habitat requirements for adult lampreys during their initial migration from the ocean. Migrating adults presumably require ample stream flows in order to migrate into smaller tributaries, relatively cool water temperatures, and cover from predation. Radio telemetry studies indicate that upstream migration generally ceases as water temperatures begin to peak and stream flows approach summer lows (Clemens et al. 2012, McCovey 2011, Starcevich et al. 2014); although movement has been reported through the summer and early fall (Robinson and Bayer 2005, Lampman 2011). Since migrating adult lampreys are photophobic and most migration occurs at night (Fox et al. 2010, Clemens et al. 2012), lampreys presumably require suitable cover from predators during the day.

4.2.1.3 Factors potentially affecting survival

Migration barriers

Migration barriers may reduce survival of adults during their initial migration from the ocean by preventing them from reaching preferred holding and spawning habitats. Even partial barriers may reduce survival and reproductive fitness due to increased energy expenditures associated with failed passage attempts and migration delays. These sites may also create migration bottlenecks that make migrants more vulnerable to predators. Several total or partial passage barriers were recently identified at road crossings of tributaries in the Eel River watershed (Stillwater Sciences 2014b) and numerous other unidentified barriers likely exist. In addition, Scott Dam on the upper mainstem Eel River is a total migration barrier, blocking access to potentially hundreds of miles of high quality holding, spawning, and rearing habitat. Approximately10 miles downstream of Scott Dam, Cape Horn Dam represents a significant obstacle to migration. Recent data suggest that less than 50% of migrating lampreys successfully pass the fish ladder, and median travel time from the bottom of the ladder to the top is 28 days (D. Goodman, USFWS, pers. comm., 2014).

Water temperature

As with other anadromous species, water temperature plays an important role in regulating metabolic rates and influences run timing, sexual maturation, and susceptibility to disease in adult Pacific lampreys (Keefer et al. 2009, Clemens et al. 2009, Clemens et al. 2012). Water temperatures that have direct and indirect adverse effects on migrating adult Pacific lampreys remain a significant data gap, but migration generally (but not always) ceases when water temperatures reach approximately 20°C (68°F) (Clemens et al. 2012, McCovey 2011, Starcevich et al. 2014). Water temperatures in the mainstem Eel River and major tributaries are generally expected to be suitable for adult Pacific lampreys during the winter and spring portions of the migration period. During the latter part of the migration period (June–August) in 2012, 7-day moving average water temperatures in parts of the mainstem Eel River, South Fork River, Middle Fork Eel River, Van Duzen River and some major tributaries exceeded 20°C (68°F) and became substantially higher later in summer in some locations (Higgins 2013). Water temperatures in the upper portions of the mainstem South Fork Eel River (above Elder Creek) and many Eel River basin tributaries remained below 20°C throughout the summer. Studies establishing water temperature criteria for migrating adult Pacific lampreys are needed before a detailed assessment of the potential impacts of water temperatures can be conducted.

Predation

For the same reasons adult Pacific lampreys are desirable as a food source for humans, they are also sought out by many aquatic and terrestrial animals: they are relatively easy to catch and they have a very high caloric content—two to five times higher per unit weight than Chinook salmon (Stewart et al. 1983, as cited in Close et al. 2002; Whyte et al. 1993). A study of seals and sea lions on the lower Rogue River indicated that Pacific lampreys can make up a high percentage (92%–96%) of their diet seasonally (Bowlby 1981, Roffe and Mate 1984). Migrating adult lampreys are preyed on by numerous species (Close et al. 1995, Cochran 2009). In the Eel River basin, seals, sea lions, ospreys, blue herons, river otters, and bald eagles have all been documented feeding on adult lampreys (Stillwater Sciences 2010). Notably, Nakamoto and Harvey (2003) documented a 470-mm Sacramento pikeminnow (*Ptychocheilus grandis*) that had consumed a 600-mm Pacific lamprey in the Eel River. Pikeminnow were illegally introduced into Pillsbury Reservoir around 1979 and within a decade had expanded throughout the mainstem Eel River and most major tributaries (Brown and Moyle 1997).

Disease

The role of disease in impacting migratory adults is unknown but is presumably a more important factor when water temperatures are higher during the latter part of the migration period. Adult Pacific lampreys in the Willamette basin have been shown to develop furunculosis, which proliferates at higher water temperatures and causes increased mortality in salmonids (Clemens et al. 2009).

4.2.2 Pre-spawning holding

4.2.2.1 Life history and distribution

Based on studies in other river systems (Robinson and Bayer 2005, McCovey 2011, Lampman 2011, Starcevich et al. 2014) and limited evidence from various observations in the Eel River (Stillwater Sciences 2010), the pre-spawning holding stage begins when individuals cease upstream movement, generally in June or July, and continues until fish begin their secondary migration to spawn, generally in March or April (Table 1). While most individuals remain stationary throughout the late summer, fall, and winter, some individuals may undergo additional upstream movements in the winter following high-flow events (McCovey 2011, Starcevich et al. 2014).

Very few holding locations have been documented in the Eel River basin (Stillwater Sciences 2014b), but holding is expected to occur throughout much of the basin. Most Pacific lampreys remain in mainstem rivers and larger tributaries during the pre-spawning holding stage (Robinson and Bayer 2005, Clemens et al. 2009, Fox et al. 2010, McCovey 2011, Starcevich et al. 2014), but some individuals hold in mid-size and smaller tributaries (Fox et al. 2010, Stillwater Sciences 2010). For example, in the Eel River basin, adults have been documented holding in the summer in relatively small streams, including Fox and Rock creeks in the South Fork Eel sub-basin (B. Trush, McBain & Trush, pers. comm. 2 May 2010), Ryan Creek, a tributary to Outlet Creek (S. Harris, CDFW, pers. comm., 21 May 2010), and Cahto Creek, a tributary to Tenmile Creek in the upper South Fork Eel sub-basin (D. Goodman, USFWS, unpubl. data, 2012).

The extent to which adult Pacific lampreys may utilize small streams for over-summer holding remains an uncertainty. It is possible that some small headwater streams provide superior water quality or other conditions preferred for holding compared with larger, lower-gradient reaches. In stream reaches of the Eel River basin where summer stream flows and water quality have become degraded, small headwater streams may play an increasingly important role for Pacific lamprey over-summer holding.

4.2.2.2 Habitat requirements

Recent radio telemetry studies have begun to shed light on habitat requirements and preferences of adult Pacific lampreys during the holding period. In general, adult lampreys appear to prefer holding in protected areas associated with large cobble or boulder substrates, bedrock crevices, man-made structures such as bridge abutments, and large wood and preferentially select glide or run habitat types (Robinson and Bayer 2005, Lampman 2011, Starcevich et al. 2014). Lampman (2011) reported that Pacific lampreys in the North Umpqua River preferentially held in the interface between habitat units, such as the heads or tails of runs and riffles. Pacific lampreys have been observed holding at a wide range of water depths, but appear to prefer relatively shallow areas (approximately 0.5 to 1.5 m) even when deeper locations are available (Robinson and Bayer 2005, Starcevich et al. 2014). These habitats are presumably selected in part because they offer protection from predators, however holding habitat selection may also be related to other microhabitat features such as water temperature or hyporheic exchange (Lampman 2011).

The exact water temperature requirements for holding adult Pacific lampreys have not been identified, but several studies have documented thermal conditions during the holding period and at specific holding locations. Starcevich et al. (2014) found that mean daily water temperatures at holding locations in the Smith River, Oregon during the summer holding period ranged from approximately 16°C to 20°C, with daily maxima from 26°C to 29°C. In the John Day River, Oregon, most holding did not begin until after summer water temperatures peaked, and water temperatures ranged from approximately 3°C to 20°C during the fall through winter holding period. Lampman (2011) reported that lampreys holding in the warmer reaches of the lower North Umpqua River sought out microhabitats with cooler water temperatures during holding and hypothesized that hyporheic exchange may be an important factor in selection of holding areas.

Clemens et al. (2009) found that water temperature during the summer holding period plays a key role in regulating maturation timing. Adult Pacific lampreys held in laboratory tanks at fluctuating temperatures that mimicked ambient river temperatures during the summer (20–24°C) had lower body weights and were significantly more likely to become sexually mature and die the following spring than those held in constant cool water treatments (13.6°C). Although fish in the warm water group matured within the typical spawning period and showed no significant difference in summer survival than the cool water group, the authors of this study suggest that excessively high water temperatures during holding could result in early maturation, which could result in a mismatch between spawning time and optimal habitat characteristics for spawning, embryonic development and larval emergence.

4.2.2.3 Factors potentially affecting survival

Because holding adults are in fresh water during both summer low flows and winter high flows, they are expected to be exposed to a variety of potential factors that may limit their success.

Habitat availability and distribution

It is unknown whether availability of suitable holding habitat has potential to limit survival and production of Pacific lampreys in the Eel River basin. Although some parts of the watershed such as the mainstem lower Eel River (which has predominately gravel and small cobble substrates) appear to have minimal preferred holding habitat, there generally appears to be ample holding habitat to accommodate the number of adults that currently return to the watershed. The maximum density of holding adults that can occur in an area of suitable holding habitat is unknown, but lampreys apparently hold in relatively high densities below certain migratory obstructions such as the Van Arsdale fish ladder (Stillwater Sciences 2010). Holding habitat quantity and distribution may play a bigger role in specific streams or watersheds within the Eel River basin. For example, if suitable physical or environmental conditions for holding are not available in or in close proximity to a stream that has high quality spawning and rearing habitats, then that stream may not be used for spawning.

Access to habitat

Migration barriers may prevent Pacific lampreys from reaching holding areas in some streams. These barriers may be particularly important in streams where conditions for holding are unsuitable downstream of a barrier due to hot water temperatures or lack of boulder substrate, but suitable upstream. Such situations where holding habitat is not available due to lack of access could result in the absence of Pacific lampreys in a stream that would otherwise be suitable for spawning and rearing.

Water temperature

Water temperatures that are lethal or that have sub-lethal impacts on the holding adult life stage have not been identified, but it is likely that hot water temperatures have adverse impacts on holding adults in some parts of the basin. Several dying and dead adults were observed in an isolated pool in Cahto Creek in September 2011 (D. Goodman, USFWS, unpubl. data, 2012). These individuals likely succumbed to high water temperatures or disease due to low stream flows. Clemens et al. (2009) found that water temperature during the summer holding period had significant impacts on maturation timing and body size, which may have implications for reproductive fitness. For example, early maturation due to excessive water temperatures could result in a mismatch between spawning time and optimal habitat characteristics for spawning, embryonic development and larval emergence.

Predation

As with migrating and spawning adults, holding adults likely succumb to some level of predation; however since they are typically hiding in areas with cover during this period, they are presumably less vulnerable than the other adult life stages. Individuals are likely more susceptible to predation in small streams or during low water levels occurring during late summer.

Disease

The incidence and types of disease in holding adults is unknown, but is presumably more prevalent in holding areas with high summer water temperatures. As discussed above, adult Pacific lampreys have been shown to develop furunculosis, which proliferates at higher water temperatures and can cause increased mortality in salmonid populations (Clemens et al. 2009).

4.2.3 Spawning migration and spawning

4.2.3.1 Life history and distribution

Following the pre-spawning holding period, Pacific lampreys undertake a secondary migration from holding areas to spawning areas. This movement generally begins in March and continues through July, by which time most individuals have spawned and died (Robinson and Bayer 2005, Stillwater Sciences 2010, Lampman 2011, Starcevich et al. 2014). Spawning has been observed to start later and last longer into the summer during cold wet springs compared with dryer, warmer years (Brumo 2006, Gunckel et al. 2009). Limited observations from the Eel River basin indicate that Pacific lampreys spawning time is comparable to that documented in other river systems in the region (e.g., Brumo et al. 2009, Gunckel et al. 2009), generally starting in March or April and continuing into June or July (Stillwater Sciences 2010). Timing is expected to vary between streams and years with different environmental conditions. Observations in the South Fork Eel River watershed suggest spawning typically peaks slightly later in the mainstem (May or June) than in the tributaries (April or May) (S. Harris, CDFW, pers. comm., 21 May 2010). Spawning surveys conducted by the WNRD during spring and summer 2014 in the Lower Eel sub-basin, and lower portions of the Van Duzen and South Fork Eel sub-basins will help refine understanding of spawning distribution and timing.

During this secondary migration, movement from holding areas to spawning areas can be upstream or downstream (Robinson and Bayer 2005, Lampman 2011, Starcevich et al. 2014). Additionally, individual Pacific lampreys have been documented spawning in multiple locations, moving substantial distances (up to 16 km) in the spring between spawning areas (Starcevich et al. 2014).

Pacific lamprey spawning has been observed in a wide range of stream sizes, but is more prevalent in higher order streams (active channel widths >15 m [49 ft]) than smaller, low-order streams (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009). They are expected to spawn in accessible stream reaches throughout much of the Eel River basin and have been documented spawning in channels draining areas ranging in size from approximately 6 km^2 (e.g., Ryan Creek) >9,000 km^2 (lower mainstem Eel River (Stillwater Sciences 2010; Stillwater Sciences and WNRD 2016). Spawning adults, redds and carcasses have been documented in the upper reaches of the mainstem Eel River near Cape Horn Dam (Stillwater Sciences 2010), and relatively high redd densities were documented in reaches of the lower mainstem Eel, South Fork Eel, and Van Duzen rivers (Stillwater Sciences and WNRD 2016).

The extent to which Pacific lampreys utilize spawning habitat in small streams is a significant data gap. In general, observations of Pacific lamprey spawning in relatively small streams in the Eel River basin are uncommon, but redds were recently documented in Booths Run (15 km^2) and Shaw Creek (14 km^2), small tributaries to Lawrence Creek in the Van Duzen River basin (Stillwater Sciences and WNRD 2016). Recent studies from other river systems indicate that Pacific lampreys generally prefer larger streams for spawning (Stone 2006, Gunckel et al. 2009), and ammocoete presence-absence surveys in lower Eel River basin tributaries only detected the species at locations in streams draining areas larger than approximately 15 km^2 (Stillwater Sciences 2014b, Stillwater Sciences and WNRD 2016). Moreover, our surveys failed to document Pacific lamprey presence in numerous small streams with apparently suitable spawning and rearing habitat, and also some relatively large streams such as Strongs, Howe, Bear, and Root creeks (approximate drainage areas of 30 km^2, 28 km^2, 20 km^2, and 17 km^2, respectively). Factors potentially explaining selection of spawning areas such as channel gradient, and proximity to suitable holding and rearing habitats are not well understood. Likewise, the roles of ammocoete presence and density and concentration of migratory pheromones (Yun et al. 2011) in attracting spawning adults to tributaries and specific spawning areas needs investigation.

4.2.3.2 Habitat requirements

Spawning habitat requirements for Pacific lampreys are relatively well understood compared with other life stages. Redds are typically constructed by both males and females in gravel and cobble substrates within pool and run tailouts and low gradient riffles (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009, Figure 3). Pacific lampreys can utilize a wide range of substrate sizes for building redds, ranging from fine gravel to large cobble. Most spawning occurs in substrate patches with dominant particle sizes ranging from approximately 10–100 mm (0.4–3.9 in) (Howard and Close 2004, Stone et al. 2006, Gunckel et al. 2009).

Spawning generally takes place at daily mean water temperatures from 10–18°C (50–64°F), with peak spawning around 14–15°C (57–59°F) (Stone 2006, Brumo 2006). The upper and lower temperatures at which spawning occurs are not well-defined, but there is likely strong selective pressure for spawning before water temperatures reach levels that are unfavorable for successful embryonic development (approximately 20–22ºC) (Meeuwig et al. 2005).

Newly constructed Pacific lamprey redds have been observed at water velocities from 0–1.2 m/s (0–4.0 ft/s) with 0.2–0.6 m/s (0.7–2.0 ft/s) most commonly used (Moyle 2002, Howard and Close 2004, Stone 2006, Gunckel et al. 2009). Pacific lamprey spawning and newly constructed redds have been observed at water depths from approximately 0.1–4.0 m (0.3–13.1 ft) (Farlinger and Beamish 1984, Howard and Close 2004, Stone 2006, Gunckel et al. 2009).

Figure 3: Pacific lamprey and redd in gravel and cobble substrates in the North Fork Eel River (photo by A. Brumo).

4.2.3.3 Factors potentially affecting survival

This section focuses on factors affecting direct spawning success and survival of spawning adults. Factors affecting survival during embryonic development within the redd (another measure of spawning success) are discussed in the following section.

Habitat availability

It is unknown whether availability of suitable spawning habitat has potential to limit survival and production of Pacific lampreys in the Eel River basin. Existing data and observations indicate that suitable spawning substrate is abundant in most low to moderate gradient stream reaches (A. Brumo, pers. obs., CDFW 2010, 2012). For this reason and due to their high fecundity, we hypothesize that spawning habitat does not typically limit Pacific lamprey populations in these areas compared with availability of fine substrates for rearing. Even in higher gradient reaches where spawning habitat is more limited, availability of fine substrate is likely to limit the population productivity more than spawning habitat.

Because lampreys spawn in space limited benthic habitats, density dependent mechanisms have the potential to influence spawning success. In general, there appears to be ample suitable spawning substrates to support relatively large numbers of spawning adults in most low to moderate gradient streams across the Eel River basin (A. Brumo, pers. obs., CDFW 2010, 2012). It is possible that in years with high spawning escapement, individuals must compete for limited spawning gravel in some areas. Additionally, even when spawning habitat is plentiful compared with the number of spawners, high spawning densities and redd superimposition could occur due to behavioral attraction to areas where other spawning fish are present. Density of spawners has been correlated with decreased survival of developing embryos in the redd in a river system that has relatively high spawning densities but where all available spawning habitat was not being utilized (Brumo 2006). Anecdotal or apparent evidence of superimposed spawning by Pacific lampreys has been cited in several studies (Pletcher 1963, Kan 1975, Brumo 2006, Gunckel et al. 2009).

Access to habitat

Another factor affecting availability of suitable spawning habitat is the presence of migratory barriers that may block access to high quality spawning areas. Several total or partial passage barriers were recently identified at road crossings of tributaries in the Eel River watershed (Stillwater Sciences 2014a) and numerous other unidentified barriers likely exist. In addition, Scott Dam on the upper mainstem Eel River is a total migration barrier, blocking access to potentially hundreds of miles of high quality spawning and rearing habitat. Approximately, 10 miles downstream of Scott Dam, Cape Horn Dam represents a significant obstacle to migration. Recent data suggest that less than 50% of migrating lampreys successfully pass the fish ladder, and median travel time from the bottom of the ladder to the top is 28 days (D. Goodman, USFWS, pers. comm. 1/10/2014). Such migration obstacles, while not complete barriers, may result in reduced reproductive success (lowered survival and fecundity) due to the additional energy expenditures associated with failed passage attempts and migration delays. The quantity and quality of Pacific lamprey habitat blocked by Potter Valley Project dams needs to be more thoroughly assessed in order to understand their population-level impacts in the Eel River basin. Low stream flows may also limit access of spawning adults into tributaries in drought years, when some streams in the Eel River basin go sub-surface (Stillwater Sciences and WNRd 2016).

Water temperature

The water temperatures that adversely affect spawning adult Pacific lampreys are largely unknown. The spawning season generally ends in late-spring or early summer when daily mean water temperatures begin to reach 18–20°C (64–68°F). This timing is likely selected in part to minimize high water temperatures during the embryonic development (Section 4.2.4). Unseasonably warm water temperatures during the spawning season are expected to result in increased incidence of disease or premature death due to increased metabolic costs.

Predation

Predation is likely a key density-independent factor affecting survival of spawning adult Pacific lampreys. The spawning life stage is expected to be considerably more vulnerable to predation than sexually immature individuals migrating from the ocean and holding adults due to their presence in shallow spawning areas, often during daylight hours. Starcevich et al. (2014) documented signs of predation on over 50% of tagged adult lampreys during the period after they emerged from holding through the spawning period. Otters, eagles, osprey, and great blue heron are just a few of the native animals documented feeding on spawning stage Pacific lampreys (Close et al. 1995, Stillwater Sciences 2010). Non-native pikeminnow may also be a significant predator on spawning adult lampreys in the Eel River (Nakamoto and Harvey 2003).

Disease

The role of disease in impacting spawning stage adults is not known. It is however likely that incidence of disease increases with increasing water temperatures during the holding and spawning periods. As discussed above, adult Pacific lampreys have been shown to develop furunculosis, which increases mortality in salmonids and is more common in higher water temperatures (Clemens et al. 2009).

4.2.4 Embryonic development

4.2.4.1 Life history and distribution

During spring and early summer spawning period, small (1.5 mm) eggs are deposited into redd substrates and hatch after approximately 15 days, depending on water temperatures (Figure 4). The yolk-sac larval stage spends approximately 15 more days in the redd gravels until resorption of the yolk-sac is complete. At this time they emerge at night and drift downstream to burrow into fine sediments and begin the ammocoete stage (Meeuwig et al. 2005, Brumo 2006). Pacific lampreys spawn over a period of 3–4 months (Gunckel et al. 2009, Brumo et al. 2009, Stillwater Sciences 2010) and offspring of earlier spawning individuals can be exposed to a suite of environmental conditions that differ markedly from those experienced by offspring of later spawning individuals. During the spring and summer embryonic development period, stream flows are generally dropping and water temperatures are increasing.

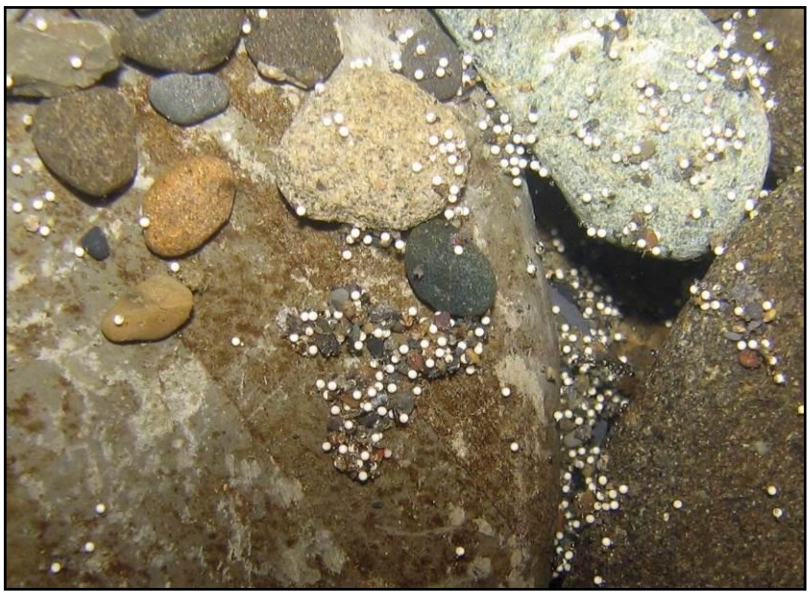

Figure 4: Pacific lamprey eggs adhered to substrate; eggs are approximately 1.5 mm in diameter (photo by A. Brumo).

4.2.4.2 Habitat requirements

Most habitat requirements for developing Pacific lamprey embryos have not been fully described. Developing embryos are known to require water temperatures below approximately 20°C (Meeuwig et al. 2005). Based on typical size of spawning substrates, most embryos likely develop within substrates with dominant particle sizes ranging from approximately 10–100 mm (0.4–3.9 in) (Howard and Close 2004, Stone 2006, Gunckel et al. 2009). Developing embryos also presumably require minimal intrusion by fine sediments and ample dissolved oxygen for successful development. These factors are discussed in more detail in the sections that follow.

4.2.4.3 Factors potentially affecting survival

Spawning density

Understanding the relationship between spawning stock and larval recruitment is essential for evaluating early life survival, yet the stock-recruit relationship has been minimally studied for the Pacific lamprey. In highly fecund fishes, there is typically a non-linear relationship between the number of spawning adults and the number of young produced (Houde 1987, Bjorkstedt 2000). Because lampreys spawn in limited benthic habitats, density-dependent mechanisms may influence their survival and recruitment. Lowered recruitment of stream-spawning fishes at higher spawner densities can result from redd superimposition by later spawning adults (e.g., Manion and Hanson 1980, Fukushima et al. 1998), and intraspecific competition for limited food or habitat resources during juvenile stages (e.g., Weise and Pajos 1998, Partridge and DeVries 1999). The latter is discussed in more detail in Section 4.2.6. Investigations of sea lamprey (*Petromyzon marinus*) population dynamics show a high amount of density-independent variation in larval recruitment, but a general reduction in recruitment at highest spawner densities (Jones et al. 2003, Haesker et al. 2003). Likewise, density of Pacific lamprey spawners was correlated with decreased survival of developing embryos (Brumo 2006). Evidence of superimposed spawning by Pacific lampreys has been cited in several studies (Pletcher 1963, Kan 1975, Brumo 2006, Gunckel et al. 2009).

Fine sediment and gravel permeability

The survival of salmonid embryos can be reduced by fine sediments infiltrating redd gravels during the incubation period (Everest et al. 1987). The key factor determining survival during egg incubation until emergence is sufficient flow of water through the spawning gravels to ensure adequate delivery of dissolved oxygen and removal of metabolic wastes. When a high percentage of fine sediment is deposited in or on the streambed, gravel permeability and interstitial flow can be substantially reduced. Reduction of gravel permeability results in progressively less oxygen and greater concentrations of metabolic wastes around incubating eggs, resulting in higher mortality (McNeil 1964, Everest et al. 1987, Barnard and McBain 1994).

While the relative impact of fine sediments on survival of Pacific lamprey embryos has not been directly studied, it is expected that high levels of fine sediments in redd gravels will reduce survival through similar mechanisms identified for salmonids. The Lower Eel, Middle Main Eel, Upper Main Eel sub-basins are all listed on the 2006 Clean Water Act Section 303(d) List of stream segments that are impaired for Sedimentation/Siltation (http://www.waterboards.ca.gov/water_issues/programs/tmdl/docs/303dlists2006/swrcb/r1_final303dlist.pdf). In addition, sediment and turbidity have been cited as potential factors limiting or impairing salmonid spawning success in the Lower Eel and Van Duzen River sub-basins (CDFG 2010, 2012). The impact of fine sediment on survival of developing Pacific lamprey embryos and whether it has population-level consequences in the Eel River warrants further investigation. Parts of the Eel River basin have historically and recently experienced intensive land use, including clear-cut logging and road building for timber production and illegal clear-cutting and poorly planned road building associated with intensive marijuana cultivation that are likely contributing to sediment impairment in many streams.

Water temperature

As with other fishes, water temperature is a crucial parameter in development and survival of lamprey embryos (Pletcher 1963, Rodríguez-Muñoz et al. 2001, Meeuwig et al. 2005). In a laboratory setting, Meeuwig et al. (2005) found a sharp decline in survival of both “fertilization-to-hatch” and “hatch-to-larvae” stages as rearing temperature increased from 18ºC to 22ºC.

Embryos reared at 22ºC were also shown to be approximately six times more likely to have developmental abnormalities than those reared at lower temperatures (Meeuwig et al. 2005). Based on the results of Meeuwig et al. (2005) it is likely that water temperatures in excess of 18–22°C during spawning and egg development may reduce embryo survival. Summer 7-day average water temperatures exceeding 24°C (75°F) were recorded in parts of the mainstem Eel River, South Fork Eel River, Middle Fork Eel River, and several major tributaries in 2012 (Higgins 2013).

Predation

Various species of fish have been observed feeding on Pacific lamprey eggs in redds during and after spawning (Pletcher 1963, Close et al. 2002, Brumo 2006, Cochran 2009) and numerous other aquatic organisms such as macroinvertebrates and crayfish are expected to feed on eggs. On the South Fork of the Coquille River, very high densities of speckled dace (*Rhinichthys osculus*) have been observed preying on lamprey eggs (Brumo 2006) (Figure 5). Three non-native minnow species [speckled dace, California roach (*Lavinia symmetricus*), and Sacramento pikeminnow] occur in parts of the Eel River basin, in very high densities in some areas. In addition, non-native warm water species such as green-eared sunfish (*Lepomis cyanellus*) and black bullheads (*Ameiurus melas*) that likely escaped from farm ponds have been detected in Tenmile Creek and are likely present in other parts of the watershed. The impact of these non-native predators on embryo survival is a factor that may limit production of ammocoetes, particularly during the warmer parts of the spawning season.

Figure 5: Speckled dace feeding on Pacific lamprey eggs (photo by A. Brumo).

Disease

As with other life stages, the incidence of disease and impact on embryo survival is unknown. It is likely that incidence of disease increases with increasing water temperatures and fine sediment level in redd gravels during development.

Redd desiccation and scour

Because Pacific lampreys spawn in the spring and water levels generally drop during the incubation period, developing redds and embryos have the potential to be desiccated, particularly if redds were constructed on river margins during high spring flows. Desiccated redds have been observed on the South Fork Coquille River, Oregon (Brumo 2006), which has similar hydrology to much of the Eel River basin. Additionally, if a channel scouring high-flow event occurs after a redd is constructed, it is possible for redds to be scoured. Both of these types of events are expected to cause high embryo mortality for a given redd, but their population-level impacts are unknown.

4.2.5 Ammocoete emergence, drift, and settlement

4.2.5.1 Life history and distribution

After embryonic development is complete, ammocoetes, approximately 8–9 mm in length (Figure 6), emerge from redd gravels into the water column at night and drift downstream until they settle into suitable rearing habitat (White and Harvey 2003, Brumo et al. 2009). Emergence and downstream drift begin approximately 30 days after eggs are fertilized, and about 15 days after hatching, depending on water temperature (Brumo et al. 2009). Downstream movement of these newly-emerged ammocoetes may continue into late summer and young-of-the-year ammocoetes continue to move downstream in relatively large numbers during their first summer, presumably seeking out suitable or unoccupied burrowing habitat (White and Harvey 2003, Brumo 2006).

Movement of newly-emerged ammocoetes is in the downstream direction from spawning grounds (Harvey et al. 2002, White and Harvey 2003, Brumo 2006). Distance moved by individuals has never been documented, but it likely depends on stream flows and availability of suitable rearing habitat. Known timing of movement is described above.

Newly-emerged and young-of-the year ammocoetes are expected to be widely distributed throughout the Eel River basin, occurring from spawning locations downstream considerable distances to rearing locations. Studies of drifting larval fishes in the Van Duzen, lower mainstem Eel, and South Fork Eel sub-basins indicated young-of-the year lamprey ammocoetes (of unknown species) were present in both the mainstems and in most major tributaries (Harvey et al. 2002, White and Harvey 2003). White and Harvey (2003) indicated that relatively few young-of-the year ammocoetes drift into the Eel River estuary based on low catches in their most-downstream sites.

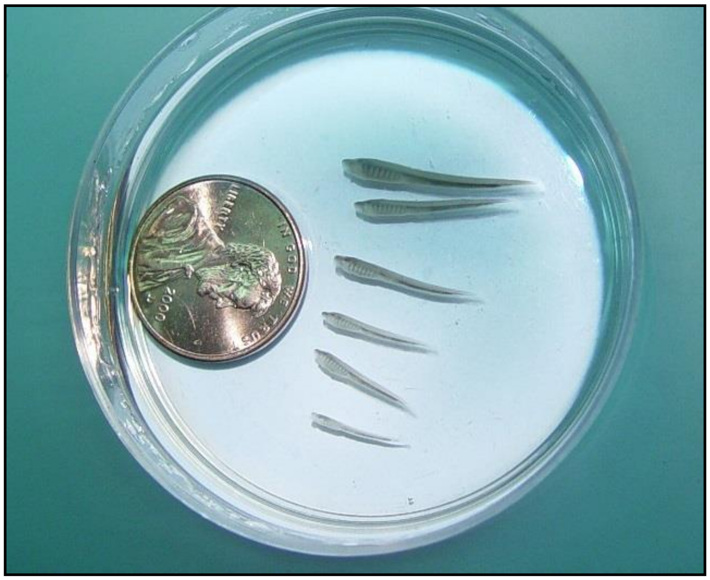

Figure 6: Newly-emerged Pacific lamprey ammocoetes (photo by A. Brumo).

4.2.5.2 Habitat requirements

Habitat requirements for young-of-the-year ammocoetes have not been precisely described, but are generally expected to be similar to that of older ammocoetes, which are detailed in Section 4.2.6. Because of their smaller size, young-of-the-year ammocoetes require less sediment depth for burrowing and are likely able to utilize some habitats that older size classes cannot. During their migration from spawning areas to rearing areas, they move only at night (Brumo 2006) and therefore likely require transitory habitats during the day until they settle into more permanent rearing habitats. Water temperature requirements for newly-emerged ammocoetes have not been described, but based on studies of sea lampreys, they presumably have a higher thermal tolerance than developing embryos (Rodríguez-Muñoz et al. 2001). Brumo (2006) documented movement of newly-emerged ammocoetes in the summer when daily mean water temperatures approached 24°C (significantly higher than the levels shown to adversely affect developing embryos in a laboratory setting); indicating young ammocoetes can likely survive temperatures in this range. However, it is unclear whether delayed mortality or sub-lethal effects occur at these temperatures Refer to Section 4.2.6 for additional discussion of water temperature requirements.

4.2.5.3 Factors potentially affecting survival

Habitat availability

Because of their small size, newly-emerged and young-of-the-year ammocoetes can presumably rear in relatively high densities and can likely burrow into shallower fine sediment patches (such as shallow layers of silt over bedrock) than larger ammocoetes. However, because ammocoetes rear in fresh water for about 4–6 years before migrating to the ocean, young-of-the-year ammocoetes may be competing with numerous other year classes of Pacific lamprey for space and in some locations they also must compete with western brook (*Lampetra richardsoni*) and river lamprey (*Lampetra ayresi*) ammocoetes which share the same habitats. In areas with high densities of ammocoetes, smaller individuals may be forced to move in search of available habitat and could be more susceptible to predation or starvation. The roles of intra- and inter-specific competition in survival of young-of-the-year ammocoetes are unknown. In addition, the proximity of suitable rearing habitat to spawning habitat likely influences survival of newly-emerged ammocoetes.

Water temperature

Summer water temperatures in parts of the Eel River basin likely exceed values that are lethal, or cause adverse sub-lethal effects, on newly-emerged ammocoetes. Studies defining water temperature criteria for this part of the life cycle are needed before the impacts of water temperature can be adequately evaluated. Refer to the habitat requirements section for more discussion of water temperature impacts.

Predation

During their movements downstream and until they locate suitable rearing habitat, young-of-the-year ammocoetes are expected to be extremely vulnerable to predation, and various fish species including salmonid fry have been reported to feed on them (Close et al. 2002, Cochran 2009). The impact of the large numbers of non-native pikeminnow and California roach that inhabit much of the Eel River on survival of young-of-the-year ammocoetes merits investigation.

Disease

As with other life stages, the incidence of disease and its impact on survival of newly-emerged Pacific lamprey ammocoetes is unknown. It is likely that incidence of disease increases with increasing water temperatures.

Entrainment

Because of their small size and weak swimming ability, newly-emerged ammocoetes are expected to be extremely vulnerable to entrainment by water diversions. This potential impact of both large and small diversions on Eel River lamprey populations is an important data gap. Section 4.2.7 provides additional discussion of entrainment.

4.2.6 Ammocoete rearing

Much of the available information on the ammocoete rearing stage of Pacific lamprey comes from other river systems and other lamprey species. Due to similarities in size, morphological structure, and habitat use of various species of ammocoetes, it is possible to draw inferences about Pacific lamprey biology, habitat, and ecology from other species, but studies of Pacific lampreys are needed to confirm these inferences.

4.2.6.1 Life history and distribution

The ammocoete stage begins after developing embryos emerge from redd gravels, drift downstream and settle into suitable rearing habitats (Figure 7), and continues until metamorphosis and outmigration to the ocean. No data are available regarding the length of time ammocoetes typically spend rearing in fresh water in the Eel River basin prior to metamorphosis, but it is likely about 4–6 years based on information from other streams in the region (van de Wetering 1998). Time spent in fresh water likely varies among Eel River tributaries and is probably influenced by conditions that affect the growth rates of each cohort (Moore and Mallatt 1980, Morket et al. 1998).

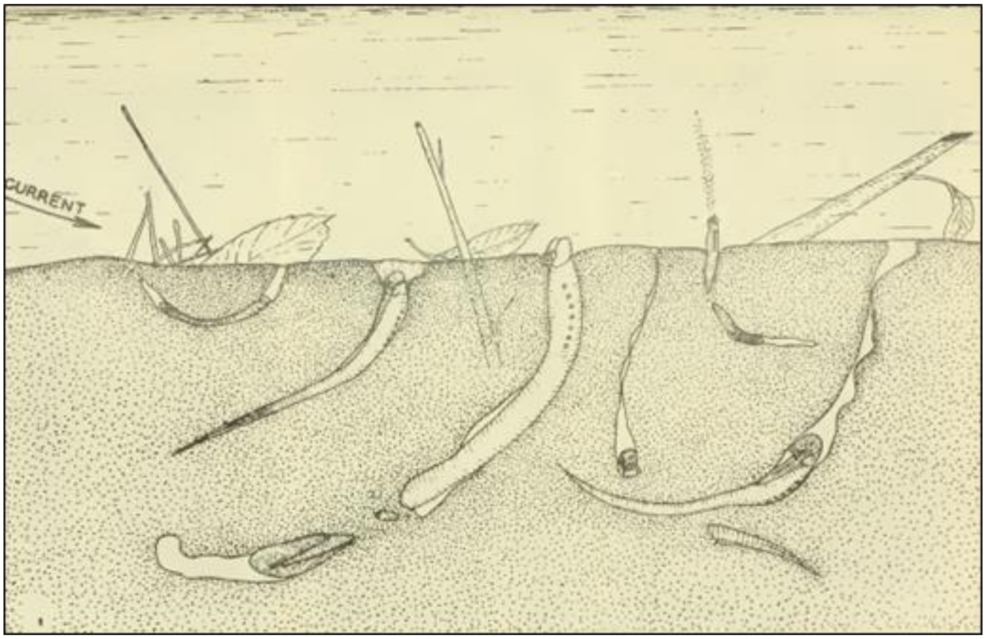

Figure 7: Lamprey ammocoetes burrowed in fine substrate (from Applegate 1950).

Ammocoetes are generally thought to be relatively sedentary once they locate a suitable rearing location, but there are very few studies examining small- or large-scale movements. Age 1 and older ammocoetes have been documented moving downstream, predominately at night, both in the late spring and summer (Brumo 2006), but more commonly with winter and spring high-flow events (van de Wetering 1998, Harvey et al. 2002, White and Harvey 2003). Winter and spring movements have been hypothesized to occur primarily due to scouring of fine substrate habitat at high flows (White and Harvey 2003), while late spring and summer movements may be related to desiccation of rearing habitats on channel margins due to dropping water levels. A study of tagged sea lampreys demonstrated that individual ammocoetes moved regularly within a 150 m^2 study area, and 60% left the area after one week (Quintella et al. 2005). Movement was primarily downstream, but some short (<8.0 m) upstream movements occurred. Recent development of PIT tags small enough (8.4 mm) to tag larger size classes of Pacific lamprey ammocoetes (>85 mm) will allow researchers to study magnitude and timing of movements by individuals.

Available data indicates that Pacific lamprey ammocoetes are relatively widespread in the Eel River basin (Stillwater Sciences 2010, Stillwater Sciences 2014b, Stillwater Sciences and WNRD 2016). Electrofishing presence/absence surveys of several small to mid-sized tributaries (drainage areas of approximately 2–50 km^2) found Pacific lamprey ammocoetes only in stream reaches with drainage areas larger than approximately 15 km^2, and the species was absent from sampled reaches of numerous smaller streams (and some larger streams)—many of which had suitable ammocoete habitat (Stillwater Sciences 2014b, Stillwater Sciences and WNRD 2016). Ammocoetes in the genus *Lampetra* (western brook or river lampreys) were detected in several streams, where Pacific lampreys were not present. The general absence of Pacific lamprey ammocoetes in small streams is largely consistent with observations that spawning is more prevalent in larger streams (Stone 2006, Brumo et al. 2009, Gunckel et al. 2009); however spawning adults have been documented in Eel River tributaries as small as 6 km^2 (e.g., Ryan Creek) (Stillwater Sciences 2010). Significant numbers of ammocoetes, presumably Pacific lamprey, have been observed as far downstream as Fernbridge (Stillwater Sciences 2010) and relatively high densities of ammocoetes (both Pacific lamprey and *Lampetra* spp) have been documented at a site sampled in the lower mainstem Eel River near Fortuna. The extent to which ammocoetes utilize the expansive areas of fine sediment downstream of Fernbridge and at the upper end of the estuary remains an important data gap. Ongoing ammocoete distribution and habitat surveys by the WNRDwill improve understanding of spatial distribution in streams of varying size and channel characteristics in the lower Eel sub-basin and parts of the Van Duzen and South Fork Eel sub-basins.

4.2.6.2 Habitat requirements

Availability of suitable burrowing substrates is widely recognized as one of the most important factors limiting the distribution of ammocoetes (Applegate 1950, Kan 1975, Torgersen and Close 2004, Stone and Barndt 2005, Graham and Brun 2007). In general, ammocoetes prefer stream-bottom habitats (typically along channel margins) characterized by silt and fine sand dominated substrates, often containing organic matter such as decaying plant material. Although ammocoetes have been found in substrates ranging in size from fine silts to gravels, they are consistently more abundant in areas dominated by fine substrates and organic matter compared with larger sand and gravel substrates (e.g., Kainuna and Valtonen 1980, Stone and Barndt 2005, CTWSRO 2012). However, ammocoetes may avoid substrates with too high a fraction of fine silt and clay, which may inhibit oxygen uptake by clogging the gills and also obstruct burrowing due to compaction (Beamish and Lowartz 1996, Smith 2009).

Other chemical and ecological variables such as chlorophyll levels, dissolved oxygen presence, preferred food items, or organic content may also influence the extent to which a patch of fine sediment is used for rearing (Sutton and Bowen 1994, Stone and Barndt 2005, Moser et al. 2007).

In addition to suitable substrate size, ammocoetes require sufficient sediment depth for successful burrowing and cover from predators. The minimum substrate depth required for rearing is unknown, but likely varies with size, with larger individuals requiring more depth. Graham and Brun (2007) found that mean depth of fine substrates was highly correlated with ammocoete presence in the lower Deschutes River, Oregon.

Lamprey ammocoetes generally rear in areas with very low to moderate water velocities and may have difficulty burrowing when velocities exceed approximately 0.3 m/s (1.0 ft/s) (Pletcher 1963). This association with low water velocities is expected since presence of fine substrates preferred by ammocoetes for rearing is typically associated with low water velocities (which result in deposition of preferred substrates).

Water temperature requirements for ammocoetes have not been fully described, but based on studies of sea lampreys, they presumably have a higher thermal tolerance than developing embryos (Rodríguez-Muñoz et al. 2001). Four lamprey species from eastern North America were found to have incipient lethal water temperatures ranging from 28°C to 30.5°C after being acclimated at 15°C (Potter and Beamish 1975), but it is uncertain whether Pacific lampreys have a similar tolerance. In the Red River, Idaho, Claire (2004) found Pacific lamprey ammocoetes in water temperatures up to 26.7°C, but reported that substrate temperatures averaged 2.2°C less than stream temperatures in the summer. It is likely that ammocoetes are able to behaviorally thermoregulate by burrowing deeper during periods of high stream temperature. Understanding the differences in temperature between burrowing habitats and adjacent streams in the Eel River may be important for evaluating the impact of water temperatures on ammocoete survival.

Maximum salinity tolerance of Pacific lamprey ammocoetes prior to metamorphosis was found to be approximately 12 parts per thousand (Richards and Beamish 1981), which likely has important implications for controlling the downstream distribution of ammocoetes in the lower Eel River and estuary.

4.2.6.3 Factors potentially affecting survival

Recent work suggests that survival of ammocoetes larger than 60 mm can be relatively high compared with other parts of the life cycle (Shultz et al. 2014). Nonetheless, as described below, there are numerous factors that affect survival of this life stage.

Habitat availability and density dependence

Limited observations indicate that rearing habitat is likely to be in short supply in many tributaries and even reaches of larger streams (e.g., South Fork Eel River) compared with spawning habitat (A. Brumo, pers. obs., Stillwater Sciences 2014b). The majority of fine-sediment rearing habitat is located in low-velocity areas, typically along stream margins or in alcoves or side channels (Torgersen and Close 2004, Stone and Barndt 2005). For this reason, complex stream reaches that have elements that slow water velocities and trap fine sediment such as large wood jams, side channels, and alcoves are important for creating ammocoete rearing habitat. In contrast, channelization reduces natural stream meanders and increases water velocities, thereby reducing depositional rearing areas (Close et al. 2002). Past channelization and bank armoring of many streams throughout the Eel River basin is likely a key factor in the reduction of ammocoete habitat.

Since ammocoetes rear in fresh water for about 4–6 years before migrating to the ocean, they may be competing for space with numerous other year classes of Pacific lamprey—and in some locations western brook and river lamprey ammocoetes. This intra- and inter-specific competition likely controls the ammocoete carrying capacity for a patch of rearing habitat. When carrying capacity is reached, some individuals must move in search of new habitat, making them vulnerable to predation, starvation, and exposure. Moreover, when rearing habitat is limited, density of rearing ammocoetes is expected to increase. Various studies have shown that ammocoetes rearing at low densities exhibit faster growth, higher survival, and earlier metamorphosis compared with those rearing at high densities (Mallatt 1983; Rodriguez-Munoz et al. 2003, Zerrenner and Marsden 2005). Metamorphosing ammocoetes collected in areas with low rearing densities have also been shown to be larger and have a greater proportion of females than those collected from areas with high rearing densities (Zerrenner and Marsden 2005). The influence of rearing densities on size and age of metamorphosis and sex ratio is important because changes in these characteristics likely result in enhanced survival and reproductive potential of the population.

Due to their multi-year freshwater residency, ammocoetes are exposed to a wide range of environmental conditions, from summer low flows and high temperatures to high winter flows and low temperatures. Potential impacts of stream flow and water temperature on habitat availability are discussed below. Factors affecting availability of suitable habitat in the summer and winter are discussed in more detail in the context of limiting factors below (Section 5).

Habitat quality and growth

Understanding patterns in ammocoete growth and the factors affecting it is a critical component of understanding population dynamics and limiting factors. Food quality and rate of growth is expected to strongly influence age at metamorphosis and outmigration (Holmes and Youson 1997) and thus may be a key factor controlling population dynamics of the species. Furthermore, like salmon (e.g., Ward et al. 1989), size at outmigration is expected to influence estuary and ocean survival and may play an important role in determining the number of adults that return to fresh water to spawn.

Numerous factors likely influence habitat quality and growth including, rearing densities, water temperatures, stream flow, and other variables such as chlorophyll and dissolved oxygen levels, and organic content (Sutton and Bowen 1994, Rodríguez-Muñoz 2003, Stone and Barndt 2005, Moser et al. 2007). A study in the South Fork Eel River found that ammocoetes grew faster in the presence of mussels, suggesting that a decline in mussel populations could have negative impacts on lamprey populations (Limm and Power 2011).

Stream flow and drought

Stream flow is expected to affect ammocoete survival by influencing both quantity and quality of rearing habitat. In the Mediterranean climate of the Eel River basin, stream flows drop substantially each year through the summer and fall months, causing much of the available ammocoete habitat on stream margins to go dry. Dropping stream flows presumably cause ammocoetes to rear in higher densities in the remaining habitat or forces them to move downstream in search of new habitat. As discussed above, ammocoetes rearing at high densities may exhibit slower growth, lower survival, later metamorphosis, and a higher frequency of males compared with those rearing at low densities. Ammocoetes displaced downstream by receding flows are likely vulnerable to predation, starvation, and exposure. Additionally, receding stream flows impact important water quality parameters such as temperature and dissolved oxygen, which may directly or indirectly affect ammocoete survival.

In drought years, impacts of low stream flows on ammocoete survival are likely more severe. For example, during the extreme drought year of 2014, large sections of many small to moderate-sized streams in the lower Eel River basin went completely dry in the summer and fall (Stillwater Sciences and WNRD 2016). Other streams had only isolated pools. Ammocoetes were not found in numerous streams during presence/absence surveys conducted in 2014. For streams that were nearly dry or had only isolated wetted pools, much of the ammocoete population may have been forced to migrate downstream to larger, flowing channels or perish in the dry reaches. For instance, in summer 2014 no wetted ammocoete habitat was present in lower Root Creek (a tributary to the Van Duzen River), but numerous ammocoetes were captured there during summer 2013 (Stillwater Sciences 2014b, Stillwater Sciences and WNRD 2016). Additionally, seemingly very high densities of ammocoetes were documented at sites in the mainstem Eel and Van Duzen rivers, supporting the hypothesis that many ammocoetes may be forced to leave drying tributaries and rear at high densities in larger streams. For those streams that go completely dry, the impact of the drought on ammocoete distribution could last for several years until recolonization occurs. It is also possible that loss of ammocoetes could result in decreased spawning or even local extirpation in these streams due to lack of the pheromone-like compounds secreted by ammocoetes that attract adults to spawning areas (Robinson et al. 2009, Yun 2011).

Water temperature

Summer water temperatures in parts of the Eel River basin likely exceed values that are lethal, or cause adverse sub-lethal effects, to ammocoetes; although many areas likely remain within a suitable range throughout the year (Higgins 2013). Potential sub-lethal and indirect effects of water temperature on ammocoetes include decreased growth and increased susceptibility to disease, parasites, or predation. Studies defining water temperature criteria for this part of the life cycle are needed before the impacts of water temperature can be adequately evaluated. Refer to the habitat requirements section above for more discussion of water temperature impacts.

Predation

Although ammocoetes are expected to be somewhat protected from predation when burrowed, a considerable number of fishes, birds, and other animals have been documented (directly or indirectly through stomach content examination) feeding on them (Pletcher 1963, Close et al. 1995, Cochran 2009, Smith 2009) and this predation has the potential to limit lamprey production in the Eel River basin. Of particular concern in the Eel River basin is the non-native and voracious Sacramento pikeminnow. Nakamoto and Harvey (2003) found that ammocoetes were a prominent prey item for both juvenile and larger pikeminnow, in some cases comprising the largest portion of their diet. Pikeminnow predation on ammocoetes was also observed in Francis Creek, a small stream in the lower Eel River sub-basin, by WNRD staff (T. Nelson, pers. comm., 12 September 2013). Tributaries in which pikeminnow are not found have likely become important refuge habitats for lamprey ammocoetes and other native fishes that they eat (White and Harvey 2001). Other documented non-native species such as green sunfish and bullheads could also adversely impact ammocoetes.

Disease

As with other life stages, the incidence of disease and its impact on survival of Pacific lamprey ammocoetes is unknown. It is likely that incidence of disease increases with increasing water temperatures.

Entrainment

Entrainment of moving ammocoetes by unscreened or improperly screened water diversions may result in significant mortality. This potential impact of both large and small diversions on Eel River lamprey populations is an important data gap. Section 4.2.7.3 provides additional discussion of entrainment.

Stranding and desiccation

As discussed above, the substantial reduction in stream flow during the summer months causes large areas of ammocoete habitat to go dry. Consequently, we expect that significant numbers of ammocoetes become stranded in off channel depressions or alcoves that may be excellent winter habitat, but that go dry during the summer or fall. Stranded ammocoetes have been documented in off-channel pits in the lower Eel River floodplain, just upstream of Fernbridge (Stillwater Sciences 2012). Connectivity between winter and summer habitats is important for minimizing losses due to stranding.

Toxins

All life stages of lampreys may be adversely impacted by chemical contaminants such as agricultural and industrial toxins in stream water or substrates, either through acute mortality or chronic impacts on fitness (CRITFC 2011). Because ammocoetes burrow into benthic habitats and spend long periods in fresh water, they are particularly vulnerable. For example, in the nearby Trinity River, Bettaso and Goodman (2008) found mercury levels in ammocoetes were an order of magnitude higher than in freshwater mussels collected at the same site. Ammocoetes also had 70% higher mercury levels in a historically mined area compared to a non-mined area (Bettaso and Goodman 2008). Some of the other common contaminants that may impact ammocoetes include other polychlorinated biphenyls (PCBs), dioxins, atrazine, flame-retardants, and various pesticides (Smith 2012, Nilsen et al. 2015). The potential impacts of elevated levels of such contaminants on lampreys in the Eel River basin require additional research.

4.2.7 Metamorphosis and outmigration

4.2.7.1 Life history and distribution

During metamorphosis, ammocoetes undergo morphological and physiological changes to prepare for outmigration and parasitic feeding in salt water, including development of eyes, a suctoral disc, sharp teeth, and well-defined fins (McGree 2008, Figure 8). Metamorphosis of Pacific lamprey has been reported to occur from July through November in British Columbia and the Columbia River basin (Pletcher 1963, Richards and Beamish 1981, McGree 2008), but timing in the Eel River is unknown. A small number of partially metamorphosed individuals (also known as transformers) were captured in Eel River basin tributaries during ammocoete surveys conducted during the late summer and early fall (Wiyot Tribe NRD, unpubl data, 2013), which is consistent with the idea that metamorphosis takes place prior to the typical fall to spring outmigration period.

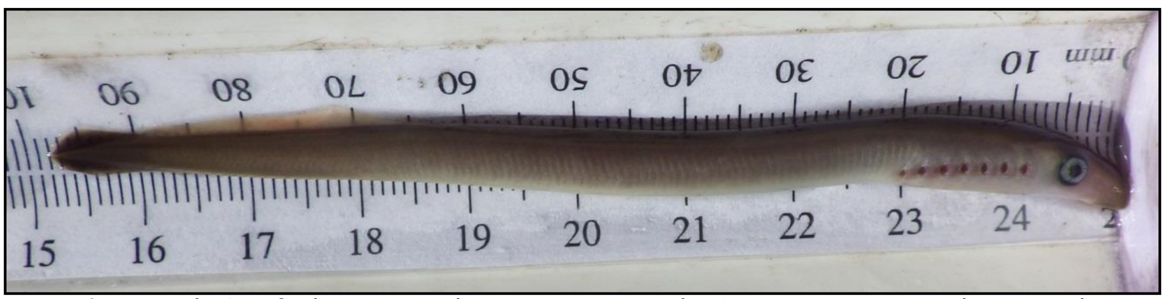

Figure 8: Juvenile Pacific lamprey undergoing metamorphosis (source: Wiyot Tribe Natural Resource Department).

Limited information is available regarding outmigration timing of macropthalmia in the Eel River basin (Stillwater Sciences 2010). Macropthalmia were periodically captured, sometimes in large pulses, during outmigrant trapping conducted on Redwood and Sproul creeks (South Fork Eel sub-basin) during April and May to monitor steelhead smolt (S. Downie, CDFG, pers. comm.). However, few conclusions about outmigration timing can be drawn from these data since traps were only operated for a part of the potential outmigration period. During year-round trapping in the upper mainstem of the Eel River, macropthalmia were captured in low numbers in all months; however movement was concentrated in late winter and spring (Ebert 2008). Pulses of movement were almost always coincident with large increases in flow (Ebert 2008). Data from other river systems also indicate that most macropthalmia migrate to the ocean between fall and spring—typically in conjunction with high-flow events (Richards and Beamish 1981, Close et al. 1995, van de Wetering 1998).

Transforming ammocoetes and macropthalmia are expected to be distributed throughout much of the Eel River basin, between ammocoete rearing areas and the ocean, and have been captured in several tributaries (Stillwater Sciences 2010, Stillwater Sciences 2014b). Utilization of the estuary is a significant data gap, both for the Eel River and in general.

4.2.7.2 Habitat requirements

Habitat requirements of this transitory life stage are generally not well known. During metamorphosis, Pacific lampreys typically move from fine substrate in low velocity areas to coarse substrates with moderate current and higher dissolved oxygen content (Richards and Beamish 1981). This change in habitat preference is thought to be related to changes in respiration occurring during metamorphosis that results in the need for higher dissolved oxygen levels. When metamorphosis is complete, they move to gravel or boulder substrate with high velocity currents (Beamish 1980, Richards and Beamish 1981). Salinity tolerance increases markedly as metamorphosis nears completion (Richards and Beamish 1981) and therefore estuarine habitats are likely important during this life stage. Time spent and habitat use in the Eel River estuary is an important data gap.

Water temperature has been shown to play a key role in initiating and controlling the rate of metamorphosis in sea lampreys (Holmes and Youson 1997), but water temperature requirements for Pacific lamprey during metamorphosis and outmigration are not known.

4.2.7.3 Factors potentially affecting survival

Stream flow timing and magnitude

Because macropthalmia have evolved to outmigrate with high stream flows, substantial changes in the seasonal timing or magnitude of high-flow events have the potential to impact survival. For example, unseasonal flow releases from dams may result in a mismatch between outmigration timing and favorable estuarine or ocean conditions. In addition, impacts of predation may increase during drought years with small or infrequent high-flow events, when macropthalmia cannot move downstream under the cover of higher, more-turbid flows.

Specifically, Eel River resource managers should take Pacific lamprey outmigration into consideration when determining how to use the 2,500 acre-feet of “block water” reserved for release from the Potter Valley Project into the upper Eel River (NMFS 2002). This potential annual flow release allows NMFS and CDFW to decide how to release water in a way that provides the most benefit to salmon and steelhead in the Eel River, but does not consider Pacific lamprey outmigration. Since there is significant overlap in outmigration timing between the species, these releases are generally expected to help Pacific lampreys, but additional analysis of the potential impacts of these flows is needed.

Growth and size at outmigration

As discussed in Section 4.2.6, food quality and growth rate is expected to strongly influence age at metamorphosis and outmigration (Holmes and Youson 1997, Morket et al. 1998). Furthermore, like salmon (e.g., Ward et al. 1989), larger individuals are expected to have higher survival in the estuary and ocean; thus size at outmigration may play an important role in determining the number of adults that return to fresh water.

Water temperature

In sea lampreys, water temperatures that were too cool inhibited metamorphosis altogether, while water temperatures that were too hot resulted in a lowered incidence and slower rate of metamorphosis (Holmes and Youson 1997). Water temperature is also expected to have important implications for Pacific lamprey growth-rate and timing of metamorphosis, which may influence survival. For example, delayed completion of metamorphosis may result in a mismatch between outmigration timing and favorable river, estuarine, or ocean conditions.

Predation

Outmigrating macropthalmia are expected to be extremely vulnerable to predation and have been documented in the diets of numerous fish and bird species (e.g., Figure 9) (Close et al. 1995, Cochran 2009). In fact, in the Columbia River they can comprise a large part of the diet (over 70% in once case) of gulls and terns seasonally (Close et al. 2002). As with ammocoetes, the impact of predation by non-native pikeminnow is a particular concern in the Eel River basin that merits additional research.

Figure 9: Macropthalmia in stomach contents of gull collected in Columbia River (photo by M. Clement, Grant County PUD).

Entrainment

Entrainment of outmigrating lampreys by water diversions can be a significant factor contributing to Pacific lamprey population decline (Goodman and Reid 2012) and its impacts should be evaluated at water withdrawal sites in the Eel River basin. In particular, the screening apparatus installed at Van Arsdale Diversion Dam in 1995 was designed to protect juvenile salmonids (NMFS 2002), but does not necessarily provide sufficient protection for outmigrating macropthalmia and ammocoetes. Additionally, the numerous smaller and often unregulated diversions across the Eel River basin may entrain considerable numbers of macropthalmia, as well as newly-emerged and older ammocoetes that are moving downstream.

4.2.8 Adult ocean stage

Despite the potential importance of the adult ocean stage in lamprey population dynamics (Murauskas et al. 2013), information on this stage is extremely limited, with most research coming from Canada and Russia (Beamish 1980, Orlov et al. 2009, Murauskas et al. 2013). No information exists on use of marine habitats by Pacific lampreys originating in the Eel River basin.

4.2.8.1 Life history and distribution

After metamorphosis, Pacific lamprey macropthalmia migrate to the ocean between fall and spring where they feed parasitically on a variety of marine fishes (Richards and Beamish 1981, Beamish and Levings 1991, Orlov et al. 2009, Murauskas et al. 2013). They remain in the ocean for approximately 18–40 months before returning to fresh water as sexually immature adults (Kan 1975, Beamish 1980).

Magnitude and patterns of movement in the ocean have not been well-described. Results from recent genetics studies suggest relatively limited marine dispersal (Spice et al. 2012); however it has been suggested that many of the Pacific lampreys documented off Russian and Alaskan coasts may originate in contiguous U.S. and Canadian waters, indicating long-distance movements (Murauskas et al. 2013). Movement within the ocean is likely dictated in large part by movements of the host species (Beamish 1980, Murauskas et al. 2013).

Ocean distribution of Pacific lampreys is not well known, but they are expected to be widely distributed across much the Pacific Ocean based on their wide freshwater distribution and the presence of wounds on diverse prey species captured in varying locations and environments (Beamish 1980, Orlov et al. 2009). Pacific lampreys are widespread off the west coast of Canada and across the North Pacific Ocean, with greater concentrations in certain areas and the vast majority of catches from waters over the shelf and continental slope (Beamish 1980, Orlov et al. 2008 as cited by Luzier et al. 2011). Pacific lampreys are thought to generally move to water deeper than 70 m soon after reaching the ocean (Beamish 1980), and most catches have been from bottom trawls in depths less than 500 m (Orlov et al. 2008 as cited by Luzier et al. 2011).

4.2.8.2 Habitat requirements

The primary known habitat requirement for ocean phase lampreys is availability of a suitable host for parasitic feeding, which is discussed below. Other potential habitat requirements are unknown.

4.2.8.3 Factors potentially affecting survival

Timing of and size at ocean entry

Timing of ocean entry and size at ocean entry are the factors that are most influenced by freshwater conditions and are therefore most relevant to meaningful restoration actions. Time of ocean entry determines what ocean conditions are experienced by young adult lampreys. For example, entering the ocean at a time when important host species are abundant off the coast of the Eel River may be critical for survival. It is likely critical for lampreys to begin feeding and growing as soon as possible after entering the ocean to avoid starvation or predation. Size at ocean entry, which is likely influenced by habitat quality and growth during the ammocoete phase (Sections 4.2.6 and 4.2.7), may also influence survival, with larger individuals (having higher swimming speed) better able to catch hosts and escape predators.

Host availability and ocean productivity

Recent analyses indicate significant positive correlations between the abundance of a number of common host species (including Pacific hake *Merluccius productus*, walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, Chinook salmon *Oncorhynchus tshawytscha*, and Pacific herring *Clupea pallasii*) and returns of adult Pacific lampreys to the Columbia River basin between 1997 and 2010 (Murauskas et al. 2013). Results of these analyses indicated that regional indices of oceanic productivity (Pacific Decadal Oscillation and coastal upwelling anomalies) help explain variation in Pacific lamprey adult returns. Based on these correlations, the authors suggest that conditions during the adult feeding phase may be the primary factor determining spawning escapement to the Columbia River. The roles of host availability and ocean productivity and their relative importance to Pacific lamprey populations relative to freshwater conditions warrant additional research.

Predation

Limited data exists on predation on ocean phase Pacific lampreys, but they have been documented in the diets of a number of marine mammals, fish, and bird species—including some of the same species they utilize as hosts (Beamish 1980, Cochran 2009) (e.g., Figure 10). The population-level impacts of ocean predation are unknown.

Figure 10: Pacific lamprey recovered from stomach of lingcod (*Ophiodon elongatus*) caught near Cape Mendocino, northern California (note potential lamprey scar adjacent to pectoral fin) (photo by T. Lucas).

4.2.9 Summary of threats to survival

Factors potentially affecting survival and distribution of each Pacific lamprey life stage in the Eel River basin are summarized in Table 2. Because Pacific lamprey life history and biological information are generally lacking, factors in addition to those shown may apply. In addition, factors affecting survival of specific life stages may or may not affect numbers of returning adult lampreys. Section 5 integrates information on life-stage-specific habitat carrying capacities and density-independent mortality to identify key population bottlenecks that likely limit the number of adult Pacific lampreys returning to the Eel River.

Table 2: Summary of threats to survival of Pacific lamprey in the Eel River by life stage and related data gaps.

Factors potentially affecting survival	Significant data gaps
Initial migration from ocean	
Migration barriers	Unknown barrier sites, amount of habitat blocked
Water temperature	Water temperature criteria and stream reaches that exceed criteria
Predation	Abundance, distribution, and impacts of primary predators
Disease	Common diseases, incidence, and possible causes
Pre-spawning holding	
Habitat availability	Habitat requirements, maximum densities, habitat distribution, impact on spawning distribution
Access to habitat	Unknown barrier sites, habitat quantity blocked
Water temperature	Water temperature criteria, delayed & sub-lethal effects, role in distribution
Predation	Abundance, distribution, and impacts of primary predators
Disease	Common diseases, incidence, and possible causes
Spawning migration and spawning	
Habitat availability	Carrying capacity, limitations on ammocoete production
Access to habitat	Unknown barrier sites, habitat quantity blocked
Water temperature	Water temperature criteria, sub-lethal effects, stream reaches that exceed criteria
Predation	Abundance, distribution, and impacts of primary predators
Disease	Common diseases, incidence, and possible causes
Embryonic development	
Spawning density	Incidence and impact of superimposition
Fine sediment	Fine sediment impacts on survival; levels of fines and key sources by watershed
Water temperature	Defined criteria, stream reaches that exceed criteria
Predation	Abundance, distribution, and impacts of primary predators
Disease	Common diseases, incidence, and possible causes
Stream flows	Incidence of redd scour (high flows) or dewatering/desiccation (low flows)
Ammocoete emergence and drift	
Entrainment	Locations, timing, magnitude, and screening of significant water diversions
Water temperature	Criteria, differences from older age-classes, sub-lethal effects, stream reaches that exceed criteria
Predation	Abundance, distribution, and impacts of primary predators

Ammocoete rearing	
Habitat availability	Carrying capacity, maximum densities, seasonal differences in habitat suitability and sediment dynamics, impacts of intra- and inter specific competition
Habitat quality	Factors affecting growth, impact on age at metamorphosis, role in population dynamics
Stream flow and drought	Ability of ammocoetes to survive desiccated streams by burrowing into hyporheic zone; extent of ammocoete movement from tributaries to larger streams as stream flows drop.
Water temperature	Water temperature criteria, sub-lethal effects, stream reaches that exceed criteria
Predation	Abundance, distribution, and impacts of primary predators
Disease	Common diseases, incidence, and possible causes
Entrainment	Locations, timing, magnitude, and screening of significant water diversions; ammocoete sizes affected; Van Arsdale diversion impacts
Instream flows	Incidence, locations, and causes of dewatering of rearing areas. Impacts on water temperature
Toxins	Incidence of common contaminants, locations, sources, and lethal and sub-lethal impacts
Metamorphosis and outmigration	
Instream flows	Impacts of annual variation in timing and magnitude of flows; impact of Van Arsdale diversion
Growth	Impact of size at outmigration on outmigration timing and ocean survival
Water temperature	Water temperature criteria, sub-lethal effects, stream reaches that exceed criteria
Predation	Abundance, distribution, and impacts of primary predators
Entrainment	Locations, timing, magnitude, and screening of significant water diversions. Van Arsdale diversion impacts
Adult ocean stage	
Timing of and size at ocean entry	Timing in relation to presence of key hosts, relationship between size and ocean survival
Host availability and ocean productivity	Ocean survival values and variation. Most common hosts for different size classes near Eel River mouth, population status of key hosts, impact of host selection on marine dispersal. Role of ocean productivity in population dynamics of key hosts and Eel River adult returns.
Predation	Key predators in the pelagic environment and potential impact on ocean survival

5 LIMITING FACTORS

This section utilizes a life-history based conceptual model that integrates information on life-stage-specific habitat carrying capacities and density-independent mortality to identify key population bottlenecks that likely limit the number of adult Pacific lampreys returning to the Eel River. This conceptual model was initially developed based on existing information presented in Stillwater Sciences (2014b), with the goal of providing a framework for understanding the factors limiting the number of adult Pacific lamprey returning to the Eel River. The model is refined here based on new information gained from recent work by the Wiyot Tribe in the Eel River, as well as other recently published studies that inform understating of factors limiting Pacific lamprey populations.

This assessment of limiting factors focuses on the Eel River basin, since it is the focus of the species management plan and more information is available there. Some aspects of the conceptual model can be generalized to other watersheds within Wiyot Ancestral Territory, but ultimately, a separate analysis focused on smaller coastal streams in Humboldt Bay, such as Freshwater Creek, would be valuable since fundamentally different factors may limit lamprey populations in these streams.

5.1 Overview and Approach

Understanding the factors limiting adult returns of Pacific lamprey is an extremely complex undertaking, particularly for a large basin like the Eel River. Use of a conceptual model provides a framework to help organize available information, identify data gaps, and ascertain key factors potentially limiting production of each life stage. This information, in turn, allows for more informed prioritization of research and monitoring needed to fill data gaps, as well as management actions that are most likely to conserve lamprey habitat and increase adult returns.

The conceptual model framework is based on fundamental principles of population dynamics, where habitat carrying capacity, survival, and abundance are linked from one life stage to the next. Habitat carrying capacity for each life stage is a function of suitable habitat area available and the maximum density of fish a given area of habitat can support. The factors affecting density, growth, and survival of each life stage determine abundance of each life stage; how these factors translate from one life stage to the next ultimately determines the population's overall dynamics and abundance of returning adults over time. Such a conceptual model is useful for identifying the life stages where habitat availability or mortality may limit production ("bottlenecks"), ultimately improving our understanding of the factors controlling abundance of returning adults.

Generally speaking, a wide range of factors may limit the size and growth potential of a fish population. As outlined in Section 4.2.9, there are a large number of factors potentially impacting survival of each Pacific lamprey life stage. While each of these factors may serve as the primary limiting factor for a given life stage under specific circumstances, the conceptual model synthesizes our current understanding of the density-dependent and density-independent factors acting on each life stage to identify likely population bottlenecks under current conditions in the Eel River basin.

In addition to understanding lamprey population dynamics at the basin scale, it is also important to understand the population structure within a regional, or metapopulation, context. The degree to which a Pacific lamprey population in one river basin interacts with and/or contributes to a population in another river basin provides an indication of how dependent one population is on another. Understanding regional population structure helps explain the extent to which the Pacific lamprey population in the Eel River basin contributes to adjacent populations (and vice versa), but maybe more importantly, the extent to which improvements to habitat and ecological conditions in the Eel River basin are likely to benefit lamprey abundance in the basin. The likely implications of Pacific lamprey population structure on controlling adult returns are discussed in Section 5.2, providing a regional context for understanding the life-history-based conceptual model presented in Section 5.3.

5.2 Implications of Population Structure on Adult Returns

Recent studies on Pacific lampreys indicate weak population structure, general lack of homing to natal streams, and the importance of migratory pheromones released by ammocoetes on spawning site selection (Section 2). These studies help illustrate the evolutionary context of lamprey population dynamics and reveal some important principles for identifying key limiting factors, as well as managing and restoring populations.

First, the role of migratory pheromones released by ammocoetes in selection of spawning streams highlights the importance of maintaining healthy ammocoete populations for attracting spawning adults. We hypothesize that ammocoete abundance in a river system plays a fundamental role in determining the number of adults that enter it from the ocean. Likewise, ammocoete presence and abundance in a tributary stream influences the extent to which adults enter it to spawn. We assume that there is a positive (though unknown) relationship between the number of ammocoetes in a stream and the number of adults that return to spawn.

Second, due to lack of homing to natal streams, not all surviving Eel River Pacific lamprey outmigrants will return to the Eel River basin to spawn. However, we hypothesize that the number of macropthalmia entering the ocean from a large river system such as the Eel River contributes significantly to the regional ocean population—which in turn sets the overall potential for adult returns to regional rivers, including the Eel River. We also hypothesize that macropthalmia leaving the Eel River have a greater chance of returning there than to other rivers, and thus in a regional context, conditions in the Eel River basin have the largest effect on its lamprey population relative to other watersheds. Lamprey production from adjacent watersheds is also likely important, but this effect would be expected to decrease with distance from the Eel River due to limited dispersal of adults in the ocean. We hypothesize that the size, habitat conditions, and lamprey population size of a basin also have a strong effect on its degree of influence on adult returns, both to the basin and to nearby basins. For these reasons, the number of macropthalmia that leave a watershed and enter the ocean is expected to play an important role in determining the number of adults that will return to that watershed in future years.

Based on these fundamental premises, understanding the factors limiting Pacific lamprey ammocoete and macropthalmia production are crucial for understanding variation in adult returns, and thus determining restoration and conservation actions that would be most beneficial for restoring and protecting the population. Key factors affecting abundance of ammocoetes and macropthalmia in the context of the larger life cycle are emphasized in the conceptual model below.

5.3 Conceptual Model for Identifying Key Limiting Factors

The conceptual model presented here integrates information on life-stage-specific habitat carrying capacities and density-independent mortality presented in Section 4. It provides a starting point for analyzing available data; developing additional hypotheses; designing studies to elucidate relationships between habitat, carrying capacity, and survival; and identifying likely population bottlenecks. Where the conceptual model does not adequately explain such relationships, or is at odds with new data and analyses, subsequent refinements to the model will be needed to improve our understanding of this complex system.

Pacific lampreys generally spend approximately one year in fresh water from the time they leave the ocean until they spawn. During the initial migration from the ocean to holding areas in the Eel River, the primary factor affecting survival is expected to be predation. Habitat availability is generally not believed to limit carrying capacity at this stage; however lack of cover in the lower Eel River during migration may result in increased predation. Once migrating adults reach holding areas, they become mainly stationary, hiding in the interstices of large cobbles, boulders, bedrock crevices, or other suitable cover elements. In most parts of the Eel River basin, these habitats appear to be relatively abundant and sufficient to accommodate far more than the number of adults that currently return to the watershed. Consequently, we generally do not expect holding habitat availability to limit the number of adults that go on to spawn. Additionally, we expect minimal predation on holding adults because they presumably remain hidden from predators during this period.

Because lampreys spawn in space-limited benthic habitats, density-dependent mechanisms such as superimposition have the potential to influence spawning success; however, there appears to be ample suitable spawning habitat to support relatively high numbers of spawning adults across most of their distribution in the Eel River basin. For this reason, we do not expect availability of spawning habitat to limit the Pacific lamprey population. Density-independent factors such as infiltration of redd gravels by fine sediment, temperature, and predation may reduce survival of embryos and newly-emerged ammocoetes to varying degrees across the watershed. However, because of the extremely high fecundity of Pacific lampreys (30,000 to 240,000 eggs), even relatively low survival may be sufficient to fully seed available rearing habitat with high densities of ammocoetes—likely in excess of carrying capacity. Consequently, the number of successfully spawning adults in any given year is not necessarily correlated to the eventual ammocoete population of that year-class.

Available data suggests ammocoete rearing habitat is relatively scarce in many areas of the basin, indicating that rearing habitat could be limiting the population under current conditions. Because ammocoetes usually spend at least four years rearing prior to metamorphosis, each year-class of ammocoetes potentially competes for space with several other year-classes (in addition to *Lampetra spp.* ammocoetes in many streams), increasing the likelihood that carrying capacity of rearing habitat would be exceeded. Even in higher gradient reaches where spawning habitat is less abundant, availability of fine substrate rearing habitat is expected to be more limiting to the ammocoete population than spawning habitat. Therefore, availability of suitable rearing habitat may be a central factor governing the number of ammocoetes and macropthalmia produced from a watershed. A better understanding of rearing habitat availability throughout the Eel River basin is needed to test this hypothesis.

Due to their multi-year freshwater residency, ammocoetes are exposed to a wide range of environmental conditions, from summer low flows and high temperatures to scouring winter flows and low temperatures. Factors affecting availability of suitable habitat in the summer and winter are discussed below in the context of habitat carrying capacity.

In the Eel River basin, stream flows drop substantially through the summer and fall months, causing much of the available ammocoete habitat to go dry, presumably forcing ammocoetes into higher densities in the remaining habitat or causing them to move in search of new habitat. Ammocoetes rearing at high densities may exhibit slower growth, lower survival, later metamorphosis, and a higher frequency of males compared with those rearing at low densities (Section 4.2.6). These density-effects may have important population impacts due to decreased survival and reproductive potential. Ammocoetes displaced downstream by receding flows are likely vulnerable to predation, starvation, and exposure. Limited observations indicate considerable areas of fine sediment habitat persist throughout the summer in lower-gradient reaches of larger tributaries, along with the South Fork Eel, Van Duzen, and mainstem Eel rivers. Whether ammocoetes displaced from tributaries during receding summer flows can safely reach such habitats, and whether these reaches contain sufficient summer rearing habitat to support them, are key questions for understanding rearing habitat limitations. Additionally, it is unknown whether conditions in these reaches remain suitable to support ammocoete migrants (many of which will remain in fresh water for one or more years longer) through subsequent summers and winters.

During extreme drought years, such as 2014 and 2015, impacts of both density-dependent and density-independent sources of summer ammocoete mortality are expected to be particularly severe. Extreme drought years may set back the population by causing high mortality of ammocoetes rearing in smaller streams, sub-lethal effects due to increased water temperatures and increased metabolic costs, decreased growth due to higher rearing densities and increased competition, and increased vulnerability to predators and disease. The extent to which ammocoetes are able to respond to and survive drought conditions warrants further research. For example, do they actively migrate downstream as water levels drop to avoid stranding and desiccation? Are they able to survive when streams go sub-surface by burrowing into moist substrates connected to the hyporheic zone? For streams that go completely dry, the impact of drought on ammocoete distribution and age structure may last for several years until recolonization can occur. It is also possible that loss of ammocoetes from a stream will result in decreased spawning in these tributaries due to lack of migratory pheromones released by ammocoetes.

During typical winter flows, substantially more fine sediment rearing habitat (the majority of which is found along stream margins) is expected to be inundated, thus summer rearing habitat may be more limiting to ammocoete survival and abundance than winter habitat in many streams. However, in the winter, ammocoetes are susceptible to high scouring flows and thus need habitat that is relatively stable and protected from high flow events or connected with the flood plain. Ammocoetes have been documented moving downstream during high flows, which may be due in part to scouring of fine sediments or other changes in habitat suitability. During these movements, finding new rearing habitat downstream is critical for survival. In years when major floods occur, lack of stable winter refuge habitat could limit the ammocoete population.

There are also numerous density-independent factors that may impact survival and abundance of ammocoetes during their protracted freshwater residence (Section 4.2.6, Table 2). Some of these factors may directly or indirectly influence ammocoete habitat suitability and availability, and thus the carrying capacity of a reach. For example, if summer water temperatures are too high for rearing in a reach with otherwise suitable habitat, the number of ammocoetes that can be supported declines. Low survival of ammocoetes due to predation or disease may also result in under-seeding of available rearing habitat. However, where rearing habitat is limited compared with the number of ammocoetes searching for habitat, mortality associated with these factors may have little impact on the overall ammocoete population (essentially, even with density-independent mortality, the ammocoete population is still in excess of carrying capacity). In some cases, however, density-independent factors may play an important role in limiting ammocoete numbers in the larger Eel River basin. For example, the apparently large areas of suitable rearing habitat in low-gradient reaches of larger streams (e.g., large mud banks in the lower Eel River) support large numbers of ammocoetes, but if ammocoetes forced to move downstream in search of habitat are exposed to high predation mortality, then the population may not attain the rearing habitat's carrying capacity in these reaches. Understanding the interactions between ammocoete habitat availability, downstream movement, and predation is important for understanding and addressing key bottlenecks to the Eel River ammocoete population.

Another factor limiting ammocoete abundance in the Eel River basin is lack of access by spawning adults to stream reaches with suitable rearing habitat. Several migratory barriers have been identified in the watershed, resulting in substantial areas of unoccupied ammocoete habitat. For this reason, remediating high-priority barriers is one of the most direct ways to enhance the population. It is also possible that Pacific lamprey spawning (and rearing) may not occur in stream reaches or tributaries with suitable habitat for reasons other than barriers. For example, if the ammocoete population was extirpated due to a past stochastic event (such as the major floods of 1955 and 1964), a stream may lack the migratory pheromones used (and potentially required) by adults to select spawning streams. For this reason, a wider distribution of ammocoetes within the Eel River basin is expected to result in a wider distribution of spawning and an increase in overall ammocoete production. Additionally, a stream may not be used for spawning if suitable conditions for holding (e.g., water temperature or boulder substrates) are not present or in close proximity, even if the stream has high-quality spawning and rearing habitats. These and other potential mechanisms may play an important role in limiting Pacific lamprey distribution, and thus overall abundance.

As discussed in Section 5.2, macropthalmia production is expected to be a central determinant of the number of adults that return to a large watershed such as the Eel River. Here we define macropthalmia production as the number of individuals entering the ocean from a watershed. The primary controls on macropthalmia production can be divided into the following two components: (1) factors influencing the number of macropthalmia that are available to outmigrate from rearing areas to the ocean and (2) factors influencing survival during outmigration.

The number of ammocoetes that survive to metamorphosis ultimately sets the baseline for the number of macropthalmia that can be produced by a watershed. Therefore, the factors most important for controlling ammocoete abundance are equally important for controlling macropthalmia production. In addition, ammocoete growth rate and age at outmigration may affect macropthalmia production and survival. The fewer years that ammocoetes spend in fresh water, the lower the risk of mortality due to predation, stranding, disease, or other factors and thus the more ammocoetes that survive to reach the macropthalmia stage. Rate of growth may also influence size at outmigration, which is expected to influence estuary and ocean survival, as is the case with salmonids. Ammocoete growth rate and size are driven by habitat and food availability and quality. Factors likely influencing growth include rearing densities, water temperatures, and other variables such as food type and organic content of rearing habitat.

The primary factor expected to affect survival during outmigration is predation. Predation rate is likely mediated by numerous interacting factors including predator distribution and abundance, timing of outmigration, instream flows, turbidity, and water temperatures. Lampreys moving downstream during high, turbid flows are expected to have higher survival compared with low clear water. Additionally, key predators such as pikeminnow are more active during periods of warm water temperature, likely resulting in higher predation on individuals moving during warmer periods.

Ocean survival can be a central factor controlling adult returns of anadromous species, but little information is available to understand the factors controlling ocean survival of Pacific lampreys. The primary factors are expected to be host availability, predation, timing of ocean entry, and size at ocean entry. Section 4.2.8 describes the potential importance of host abundance on ocean survival as measured by adult returns. Timing of ocean entry and size at ocean entry are the factors most influenced by freshwater conditions and are therefore most relevant to meaningful restoration actions. Time of ocean entry determines what ocean conditions are experienced by young adult lampreys. For example, entering the ocean at a time when important host species are abundant off the coast of the Eel River may be critical for survival. It is likely essential for lampreys to begin feeding and growing soon after entering the ocean to avoid starvation or predation. Size at ocean entry, which is influenced by habitat quality and growth during the ammocoete phase, likely also influence survival, with larger individuals having higher swimming speeds and thus greater ability to catch hosts and escape predators.

In summary, based on our current understanding, the conceptual model indicates that the following are likely among the most important factors for limiting Pacific lamprey adult returns to the Eel River basin:

- adult access to and use of spawning habitat;
- ammocoete rearing habitat availability, survival, and growth;
- survival of macropthalmia during outmigration; and
- ocean survival.

The studies needed to better understand the extent to which these key factors limit the population and the underlying environmental and ecological factors causing these limitations are outlined in Section 6.

6 RESEARCH RECOMMENDATIONS TO ADDRESS KEY UNCERTAINTIES

There are numerous remaining gaps in our understanding of Pacific lampreys in streams within Wiyot Ancestral Territory (e.g., Section 4.2.9, Table 2) and extensive research is needed to address them. As described in Section 7.1, the WNRD and its partners have put in considerable effort to study this species in the Eel River, implementing the first phases of a structured research and monitoring program that has expanded our understanding of the species and contributed invaluable information for developing this plan. In general, we recommend prioritizing additional research and monitoring to fill important gaps in understanding of factors thought to be most limiting to adult returns and test hypothesis about these factors (Section 5). For this reason, key studies and analyses are organized in Section 6.1 by the factors currently thought to be most important for limiting Pacific lamprey adult returns to the Eel River basin. Various other studies needed to improve our overall understanding of the species' life history, distribution, and habitat requirements are listed in Section 6.2.

Importantly, continued implementation of the WNRD Pacific lamprey multi-life-stage, long-term monitoring program in the lower Eel River study area (Stillwater Sciences and WNRD 2016) is critical for understanding distribution, status, and population dynamics of the species, and should therefore be prioritized.

6.1 Key Studies and Analyses

Studies of Eel River Pacific lamprey should be focused on filling key information gaps and testing hypotheses regarding those factors that are currently considered most likely to be limiting numbers of returning adults, as based on the conceptual model presented in Section 5. Because restoration and management measures will likely be restricted to the freshwater habitats used by lampreys, most studies should address factors that apply to these life stages rather than the ocean phase. Finally, because of the focus on restoring the Pacific lamprey population, priority should be placed on studies that may inform and lead to feasible restoration actions, both near- and long term.

Many of these critical uncertainties in our understanding of habitat limitations and population dynamics are infeasible to study at the scale of a major river system like the Eel River. For this reason, we recommend selecting smaller, more manageable watersheds to more intensively study and monitor to address certain data gaps. Conducting studies in Lawrence and/or Bull Creeks where intensive monitoring is specified in the WNRD long-term monitoring plan (Stillwater Sciences and WNRD 2016) should be considered. However, depending on the questions of interest, working in other watersheds facing different impacts (e.g., more intensive water diversions) or where complementary studies have been conducted or planned by other entities may also be warranted.

6.1.1 Adult access to and use of spawning habitat

Lack of access to or use of available spawning habitat is a clear-cut factor limiting the Eel River Pacific lamprey population since it results in large areas of suitable habitat that are not utilized. We recommend the following steps to improve understanding of the effects of spawning habitat availability and use on population:

- Continue to document locations of and assess potentially important migration barriers and quantify the amount of habitat inaccessible due to known barriers. Refer to Stillwater Sciences (2014b) for a prioritized list of potential sites that require evaluation.
- Assess the quantity and quality of Pacific lamprey habitat blocked by Potter Valley Project dams in order to understand population-level impacts to Pacific lampreys. This assessment may take advantage of data collected by the River Institute at Humboldt State University as part of ongoing efforts to assess salmonid habitat in this part of the watershed.
- Evaluate distribution of holding locations relative to spawning and rearing locations to help understand whether distribution of holding habitat may limit use of otherwise suitable streams by Pacific lampreys.
- Investigate how other factors such as water temperature and stream flow affect access to holding and spawning areas.
- Investigate the role of ammocoete presence in limiting spawning distribution. Identify streams lacking ammocoetes, but containing suitable spawning and rearing habitat characteristics to inform potential for reintroduction.

6.1.2 Ammocoete rearing habitat availability, survival, and growth

The limiting factors conceptual model indicates both density-dependent and density-independent factors acting on the ammocoete life stage may be play critical roles in limiting the Eel River Pacific lamprey population. We recommend designing and implementing studies to improve understanding of factors affecting ammocoete habitat, survival, and growth, including:

- Assess availability of suitable ammocoete habitat relative to suitable spawning habitat to test the hypothesis that ammocoete habitat is limiting. This type of assessment may be best applied to smaller, intensively-studied focal watersheds (such as Lawrence or Bull creeks). Assessment reaches should be stratified by stream size and channel gradient to help understand how these factors affect relative availability of spawning and rearing habitats.
- Estimate ammocoete densities in suitable habitat to help assess the extent to which carrying capacity of rearing habitat is “seeded”.
- Assess seasonal and annual changes in suitable ammocoete habitat area and densities to help test hypotheses about summer versus winter rearing habitat limitations and impacts of drought/low flows.

- Describe ammocoete movements from rearing areas as flows drop between spring and fall to assess impacts of shrinking habitat area and test for density-dependent movement. This assessment could be accomplished by PIT-tagging ammocoetes and documenting seasonal movements in and out of rearing areas in relation to environmental variables of interest.
- Continue to assess quantity and quality of ammocoete rearing habitat in the lower reaches of the Eel, South Fork Eel, and Van Duzen rivers to help understand the role of these locations play in habitat carrying capacity of the larger basin. Document ammocoete use of these reaches and estimate densities to improve understanding of the role of these larger river habitats in population dynamics.
- Design studies to assess factors limiting ammocoete distribution (i.e., why are they missing from certain streams or reaches?), including the roles of water temperature and other water quality parameters and proximity to suitable holding and spawning habitats.
- Assess population-level impacts of Sacramento pikeminnow predation on ammocoetes. Evaluate predation across the river network (varying stream sizes) and in different seasons to understand the relationship with seasonal changes in ammocoete movement, habitat availability, and water temperatures.
- Continue collecting data on presence and quantity of large woody debris in relation to ammocoete presence and abundance to inform rearing habitat restoration strategies.
- Design studies to evaluate and document the impacts of water diversions and drought on water quality and stream flow as related to ammocoete habitat availability, movement, and survival. Investigate the ability of ammocoetes to survive stranding and desiccation. Consider collaborating with ongoing and planned instream flow assessments in the watershed.
- Using data from long-term monitoring, assess impacts of drought on ammocoete presence and age-structure in streams that go dry in some years.

6.1.3 Macrophthalmia production

To improve understanding of factors controlling macrophthalmia production, we recommend the following studies:

- Investigate effects of ammocoete density and habitat quality on ammocoete growth, size at outmigration, and age of metamorphosis by analyzing length-frequency data of ammocoetes and macrophthalmia from different parts of the basin (with varying habitat quality and densities). Possibly recapture PIT-tagged individuals from study reaches seasonally to evaluate individual growth.
- Assess impacts of pikeminnow predation on macrophthalmia throughout the outmigration period through examination of stomach contents and by estimating pikeminnow population size.
- Evaluate use of estuary habitat by metamorphosing ammocoetes and macrophthalmia.
- Investigate impacts of Potter Valley Project “block water” releases on outmigration timing and survival during outmigration in the upper mainstem Eel River and make recommendations for considering lamprey in planning these releases.
- Assess entrainment of ammocoetes and macrophthalmia at the Van Arsdale diversion.

6.1.4 Ocean survival

We recommend using existing information on lamprey host species distribution and abundance and the results of ongoing and future research to better understand factors that may control lamprey populations during the ocean phase. Field studies on ocean population dynamics should for the most part be avoided due to the complexity and cost of conducting research on this phase of the lamprey's life history, and because such factors would be difficult to target for restoration or management measures by the Tribe.

To improve understanding of factors controlling ocean survival, we recommend designing studies that address the following:

- Assess macrophthalmia use of the estuary and time of ocean entry.
- Expand knowledge of presence and abundance of key marine host species in near shore waters off the Eel River in relation to time of ocean entry.
- Locate and review records of lampreys in available regional fisheries data and coordinate with those monitoring ocean fisheries to collect more data on lamprey catches and scars on hosts.
- As more long-term adult monitoring data are collected for the Eel River from spawning and creel surveys, conduct analyses of relative abundance versus ocean prey and ocean conditions indicators to better understand ocean survival.

6.2 Other important research needed to address data gaps

Listed below are measures needed to address data gaps that may not directly inform primary limiting factors hypotheses, but that are important general data gaps that need to be addressed to improve our overall understanding of the species' life history, distribution, and habitat requirements in the Eel River basin:

- Continue to evaluate the extent to which Pacific lampreys utilize small streams for holding, spawning, and rearing, and factors explaining upper distribution of each life stage.
- Describe movement rates and patterns of migrating adults specific to the Eel River basin to help identify key holding locations, habitat preferences, and potential threats during this part of the life-cycle.
- Expand on monitoring of the adult population entering the river from the ocean to improve knowledge of escapement and timing. This could potentially be accomplished through deployment of a dual frequency identification sonar (DIDSON; http://www.soundmetrics.com/) that allows passive counts of migrating fish in turbid waters.
- Assess the prevalence of the ocean-maturing adult life history strategy in the Eel River basin and potential differences in timing, distribution, and movement patterns between ocean-maturing and stream-maturing life histories.
- Work with other lamprey biologists around the region to design and implement studies to develop meaningful water temperature criteria for each life stage (optimal, sub-optimal, acute stress, lethal), which will also allow more realistic assessment of the role of water temperature in distribution and survival of each life stage in the Eel River.
- Analyze water quality and temperature data for Eel River basin to determine areas that may affect distribution or survival of lampreys at various life stages, including from diseases that may be exacerbated high water temperatures.

- Study the impacts of past and present intensive land use activities on habitats used by key life stages to identify the most impacted locations in the watershed and inform restoration.

7 MANAGEMENT, CONSERVATION, AND MONITORING

7.1 Existing Measures

Very few management and conservation measures that directly address Pacific lamprey management objectives in the Eel River basin or other parts of Wiyot Ancestral Territory have been implemented to date. This is due in part to a historical lack of research and monitoring of the species (owing to lack of funding and interest by most state and federal fisheries managers and other stakeholders), which has limited the ability to make and implement informed management recommendations. For this reason, recent activities by the Wiyot Tribe have focused on research and monitoring, including conducting initial data syntheses and studies needed to fill data gaps improve understanding of basic biology, distribution, and limiting factors. Ultimately, information gained from these efforts will help identify and prioritize effective management and conservation measures. In addition, USFWS, in collaboration with other stakeholders, has initiated a range-wide planning and species conservation effort to improve the status of Pacific Lamprey throughout their range by helping implement research and conservation actions. Finally, the State of California has listed Pacific lamprey as a “Species of Special Concern”, which conveys some regulatory protections to the species. These existing tribal, federal, and state activities and protections are detailed below.

7.1.1 Wiyot Tribe Research, Assessment, and Monitoring

In recent years the WNRD has put into action a systematic research and monitoring program with the principal goal of improving the overall health of the Eel River ecosystem, with a focus on restoring Pacific lamprey abundance and distribution and protecting existing habitats. Activities conducted in the Eel River basin in support of this goal include:

- An initial summary of information and identification of research needs for Pacific (Stillwater Sciences 2010)
- A basinwide evaluation of barriers to Pacific lamprey migration (Stillwater Sciences 2014a) and ongoing plans to remediate lamprey passage problems in the basin.
- A conceptual framework for identifying factors limiting lamprey production in the basin (Stillwater Sciences 2014b).
- Development and implementation of a multi-life stage monitoring program (Stillwater Sciences and WNRD 2016) that includes:
    - ammocoete distribution surveys in the lower portions of the basin;
    - pilot monitoring of ammocoete and spawning relative abundances in index reaches;
    - design and implementation of creel surveys to monitor tribal harvest, run timing, and, relative abundance of adult Pacific lamprey entering the Eel River from the ocean; and
    - a long-term monitoring plan that includes considerations for site selection, timing and periodicity of monitoring, survey protocols, and analysis and reporting metrics for ammocoete, spawning, and creel surveys.

Moreover, the WNRD, in partnership with Stillwater Sciences, Humboldt State University Sponsored Programs Foundation (SPF), and CDFW has recently advanced efforts to (1) compile and summarize available information on Pacific lamprey in Humboldt Bay tributaries (Stillwater Sciences 2016) and (2) synthesize data on migrating and spawning adults collected by SPF and CDFW in Freshwater Creek, a major tributary to Humboldt Bay (Stillwater Sciences et al. 2016). The outcomes of this synthesis include:

- description of timing of adult Pacific lamprey entry into Freshwater Creek and collection of basic biological data (length, maturity, sex) on adult migrants;
- description of adult Pacific lamprey movement patterns from time-of-entry into fresh water until spawning; and
- description of abundance, timing, and spatial distribution of spawning adult Pacific lamprey.

In addition to these completed activities, the WNRD has proposed to conduct population surveys and diet studies of the non-native, predatory Sacramento pikeminnow and develop and test approaches for effectively monitoring and suppressing them. Evaluating and addressing the impacts of predation by pikeminnow has been identified as a pressing need, since the species considered to be a significant factor limiting recovery of the Eel River Pacific lamprey population, as well as populations of other important native species (Brown and Moyle 1997, Nakamoto and Harvey 2003, Stillwater Sciences 2014b). Although this proposed work was not funded by USFWS, pikeminnow predation was identified as a key threat to Eel River lampreys by USFWS in its *Pacific Lamprey Assessment and Template for Conservation Measures in California* (Goodman and Reid 2012) and *North Coast California PLCI Implementation Plan* (Goodman and Reid 2015).

7.1.2 Federal Protections and Conservation Efforts

7.1.2.1 United States Fish and Wildlife Service

In 2003, USFWS received a petition to list Pacific lamprey under the Endangered Species Act (ESA) (Nawa 2003), but species status review was halted after the "90-day-finding" stating that information available to the agency at that time did not warrant full consideration for ESA listing of the species (U.S. Office of the Federal Register 2004). The status of Pacific lamprey has remained a concern to Native American tribes, conservation organizations, agencies, and biologists across their range.

To encourage regional implementation of research and conservation actions aimed at restoring and protecting Pacific lamprey populations and avoiding the need for ESA-listing, USFWS initiated the Pacific Lamprey Conservation Initiative (PLCI). This structured and collaborative initiative has resulted in production of several documents to help guide planning and conservation efforts throughout the species' range. Key outcomes and work products associated with the initiative that may inform species management in the Eel River basin include:

- Considering Pacific lampreys when implementing instream activities (Streif 2009).
- Best management practices to minimize adverse effects to Pacific lamprey (USFWS 2010).
- Pacific lamprey assessment and template for conservation measures (Luzier et al. 2011).
- Pacific lamprey assessment and template for conservation measures in California (Goodman and Reid 2012).
- Regional implementation plan for measures to conserve Pacific Lamprey, California - North Coast Regional Management Unit (Goodman and Reid 2015).
- Pacific Lamprey Data Clearinghouse, with the goal of enabling and enlisting USFWS partners to address information needs identified in the Pacific Lamprey Conservation Agreement to promote Pacific lamprey conservation through (1) collaboratively

collecting occupancy and distribution data; and (2) providing a Pacific lamprey data clearinghouse for all partners.
https://www.sciencebase.gov/catalog/item/53ad8d9de4b0729c15418232

In 2012, the PLCI also finalized a *Conservation Agreement for Pacific Lamprey,* signed by federal and state agencies and Northwest Tribes, including the Wiyot Tribe. The Agreement represents a cooperative effort among natural resource agencies and tribes to reduce threats to Pacific Lamprey and improve their habitats and population status. Cooperative efforts through the Agreement intend to: a) develop regional implementation plans derived from existing information and plans; b) implement conservation actions; c) promote scientific research; and d) monitor and evaluate the effectiveness of those actions.

Relevant management recommendations from the PLCI plans and documents listed above are incorporated into recommendations for management and conservation of Pacific lamprey within Wiyot Ancestral Territory (Section 7.2).

Notably, USFWS explicitly recognizes the need to work closely with tribes in implementing the PLCI, stating that "the Pacific lamprey is a tribal trust species and as such the USFWS recognizes tribal treaty and other rights, interacts with tribes on a government to government basis, and strives to conduct its programs and actions in a manner that protects tribal trust resources, including fish and wildlife resources and their associated habitats" (Luzier et al. 2011).

7.1.2.2 Bureau of Land Management

The Bureau of Land Management (BLM) maintains a list of "sensitive" species that are not ESA-listed, but require special management consideration to reduce the need for listing. The Pacific lamprey is included as a sensitive species on this list. The manual that establishes policy for management of BLM sensitive species found on BLM-administered lands can be downloaded here:
http://www.blm.gov/style/medialib/blm/wo/Information_Resources_Management/policy/blm_manual.Par.43545.File.dat/6840.pdf

Activities occurring on BLM lands both within and outside Wiyot Ancestral Territory in the Eel River Basin and Humboldt Bay watershed can impact the species, and therefore it is important to coordinate management strategies with the agency.

7.1.2.3 USDA Forest Service

The USDA Forest Service (USFS) maintains a list of species that need special management to maintain and improve their status on National Forests and Grasslands, and prevent a need to list them under the Endangered Species Act. Pacific lamprey are included on this list for the Pacific Southwest Region (Region 5) for both the Six Rivers and Mendocino National Forests, which contain land in the Eel River basin.

While there is no USFS land within Wiyot Ancestral territory, activities occurring on these lands in the Eel River basin can impact the species and therefore it is important to coordinate management strategies with the agency.

7.1.3 State of California Protections and Conservation Efforts

7.1.3.1 Species Status and California Environmental Quality Act

The Pacific lamprey is listed by the state of California as a Species of Special Concern, with a status rating of "*Moderate Concern*" (Moyle et al. 2015, CDFW 2016). This rating denotes the species was "considered to be under no immediate threat of extinction but were in long-term decline or had naturally small, isolated populations which warrant frequent status re-assessment…." The rating was designated to the species because: "Pacific lampreys apparently still occupy much of their native range in California, but evidence suggests that large declines may have occurred in the past 50 years. Pacific lampreys no longer have access to numerous upstream habitats blocked by large dams or other impassable structures and they are no longer present in streams at the southern end of their range. The large runs that once occurred in coastal streams such as the Eel and Klamath have dwindled to a fraction of their former size" (Moyle et al. 2015).

Additionally, in their account for Pacific lamprey as a state Species of Special Concern, Moyle et al (2015) makes general management recommendations for the species based on a statewide information review. Where relevant to species management in the Eel River, these recommendations are referenced or used to inform management recommendations presented in Section 7.2 below.

While, "Species of Special Concern" is an administrative designation and carries no formal legal status, the intent of the designation according to the state (http://www.dfg.ca.gov/wildlife/nongame/ssc/) is:

- "to focus attention on animals at conservation risk by the Department, other State, local and Federal governmental entities, regulators, land managers, planners, consulting biologists, and others;
- stimulate research on poorly known species;
- achieve conservation and recovery of these animals before they meet California Endangered Species Act criteria for listing as threatened or endangered."

The California Environmental Quality Act (CEQA) requires that Species of Special concern must be included in an analysis of project (e.g., development, infrastructure, or restoration) impacts if they can be shown to meet the criteria of sensitivity outlined in the act. In general, the level of "impact significance" of a project for a Species of Special Concern is based on whether it has a substantial adverse effect to the species, either directly or through habitat modifications. If a project impact is identified as having potentially significant impacts by a required Initial Study, CEQA requires preparation of a Mitigated Negative Declaration describing impacts and how revisions to the project would avoid the significant effects, or reduce them to a less-than-significant level, and there is no substantial evidence that the revised project would result in a significant environmental effect. Alternatively, if the Initial Study requires that the project will have a significant impact, a draft Environmental Impact Report (EIR) is required to inform public agency decision makers of the significance of environmental effects, minimization measures, and alternatives. Refer to Sections 15063 and 15065 of the CEQA Guidelines for more information on how an impact is identified as significant (http://resources.ca.gov/ceqa/guidelines/art5.html). Due to this relatively new designation, it is important to educate various stakeholders and project proponents, including regulatory agencies, of the need to consider Pacific lamprey in CEQA analyses.

7.1.3.2 Harvest Regulation

Pacific lamprey harvest is covered generically under "lamprey" in the 2016–17 California Freshwater Sport Fishing Regulations. Harvest of the species is open all year, except for closures listed under district or special regulations (which do not include the Eel River), with a daily harvest limit of five fish. Allowable methods of take include, hand, hook, spear, bow and arrow fishing tackle, or dip net. However, fish tackle (hook and line) is not permitted during season closures for trout and salmon and spear and bow and arrow fishing is not permitted in "designated salmon spawning areas" (https://www.wildlife.ca.gov/regulations).

7.2 Recommended Measures

Restoration and conservation activities should be aligned with the primary management goals set forth in Section 1.3 of this plan. Specifically, management measures should focus on remediating or reducing the impacts of factors thought to limit the size of the returning adult Pacific lamprey population in the Eel River, to promote a sustainable population large enough to fulfill the historical ecological functions of the species while allowing ample subsistence harvest by the Tribe. Based on our current understanding of key limiting factors, management actions that (1) improve adult access to and use of spawning habitat (2) increase ammocoete rearing habitat availability, survival, and growth, (3) augment survival of macrophthalmia during outmigration, and (4) improve ocean survival should be prioritized.

7.2.1 Restoration and Monitoring Measures

We recommend working towards the following restoration activities, some of which can be done in the near term and some of which require further study and design:

- Continue pursuing the Wiyot Tribe's ongoing research and monitoring program (Section 7.1.1) and seek funding for research to address key data gaps (Section 6.1).
- Coordinate with Caltrans and other landowners, as well as the California Fish Passage Forum Passage to implement lamprey barrier remediation through retrofits or culvert replacements with bridges or natural bottom crossings, as recommended by Stillwater Sciences (2014a).
- Implement improvements to summer and winter ammocoete rearing habitat and seasonal connectivity between rearing habitat areas. Specifically, design projects that restore habitat complexity and channel sinuosity in channelized reaches to create low-velocity areas that capture and store fine sediments under varying flows. One approach is placement of large wood structures to improve complexity and encourage development of side channels and alcove habitats.
- Continue to seek funding for evaluating the feasibility and efficacy of, and implementing, a pikeminnow monitoring and suppression program to improve ammocoete and macrophthalmia survival in the Eel River.
- Explore feasibility of reintroduction. In some streams that contain high quality habitat characteristics, but where Pacific lampreys are not present, exploring the feasibility and benefit of reintroduction may be warranted. The suitable river strategy for selecting spawning streams highlights the potential importance of ammocoete populations for attracting spawning adults. For this reason, planting ammocoetes (or spawning adults to produce ammocoetes) to help attract natural spawning in future years could accelerate restoration of the population. This strategy has been used successfully in the Umatilla

River, Oregon (Close et al. 2009) and may be applicable to streams in the Eel River basin that are recovering from a combination of past intensive land use and large flood events. Following completion of ongoing distribution and habitat surveys, the WNRD may be able to identify candidate streams for possible reintroduction.

- Lobby NOAA Fisheries to consider Pacific lamprey life history and habitat requirements when planning annual Potter Valley Project "block water" releases in the upper mainstem Eel River.
- Work with applicable state and federal agencies to insure Best Management Practices (Streif 2009, USFWS 2010) are being implemented to reduce and prevent habitat degradation resulting from land use activities, including extractive activities (instream gravel mining, timber harvest, grazing) and restoration activities.
- Work with applicable state and federal agencies to require that instream projects and diversions address lamprey habitat and life history requirements and provide appropriate mitigation measures as required by law.

As additional studies and analyses are conducted and our understanding of the primary factors limiting the lamprey population is refined, additional and more detailed restoration approaches that target key limiting factors can be designed and implemented.

Ultimately, there is a need for a more holistic approach to fisheries restoration in the Eel River basin, one that encourages those working to restore habitat for a single species, such as coho salmon, to consider the needs of other important species, such as Pacific lamprey. To achieve this goal, it is necessary to continue educating biologists and other stakeholders focused on salmonid restoration regarding the importance of lampreys and their habitat requirements.

7.2.2 Regional and Agency Coordination

In general, to help addresses gaps and work toward Pacific lamprey restoration and conservation, we recommend coordination between the WNRD, USFWS, CDFW, and other local, state, federal, and tribal entities. In all cases, it is important to work cooperatively and share information to encourage collaboration, avoid duplication of effort, and accelerate restoration and protection of this important species. Regional coordination of management, restoration, and monitoring is particularly important for Pacific lamprey because their relative lack of homing and weak population structure compared with anadromous salmonids means activities occurring in one watershed may impact populations in nearby watersheds (Section 2 and Section 5.2).

Where possible, we recommend working within the structure of the ongoing USFWS Pacific Lamprey Conservation Initiative (Luzier et al. 2011, Goodman and Reid 2012) and its regional implementation plan for the northern California coast (Goodman and Reid 2015). Restoration and conservation activities should address relevant priorities set-forth in the various USFWS PLCI documents to the extent possible.

Additionally, we intend to provide Eel River lamprey distribution data to the USFWS PLCI Pacific Lamprey Data Clearinghouse as funding and time allows.

7.2.3 Education and Outreach

The Pacific lamprey is an understudied species that has been largely neglected by many scientists and fisheries managers. Additionally, many in the public have the negative perception that it is a creepy, snake-like creature with no value that kills other more desirable fish species, rather than an integral part of the ecosystem. For these reasons, educating both biologists and the general public about Pacific lamprey ecology, restoration, and conservation is an important part of the larger species management strategy. Recommendations for education and outreach include:

- Educate biologists working in the Eel River and Humboldt Bay watersheds on lamprey identification and methods for consistent collection of biological data (e.g., measurement of intra dorsal length). Encourage them to include lamprey data and observations in published reports or share data with the Wiyot Tribe or the USFWS PLCI.
- Expanded coordination with biologists from local timber companies, such as Humboldt Redwood Company and Green Diamond Resource Company, to summarize lamprey data collected through their ongoing fish and habitat monitoring in the region.
- Encourage local biologists and restoration practitioners to consider lamprey-specific habitat requirements when designing and implementing restoration projects and follow Best Management Practices (Streif 2009, USFWS 2010).
- Continue to educate and involve Wiyot Tribal youth in educational programs and opportunities to become engaged in and learn about various WNRD projects, including lamprey research and monitoring.
- Work with schools and watershed groups to educate local youth on the ecology and conservation of local rivers, including the important role of Pacific lampreys.
- Educate various stakeholders and project proponents, including regulatory agencies, of the need to include Pacific lamprey in CEQA analyses.

7.3 Management Plan Refinement and Adaptive Management

As described above, development of this Pacific Lamprey Species Management plan is an iterative process. Due to the limited amount of information on the species in the Eel River basin and other watersheds in the region, making specific and informed management and conservation recommendations is challenging and in some cases premature. We envision that this version of the plan will be the first of several iterations and will require additional funding to refine, expand, and implement. Ideally, this plan will be updated approximately every three to five years or when substantive new information becomes available to fill important data gaps, inform existing management recommendations, or add new management recommendations. To accelerate our ability to refine this plan and make meaningful recommendations, it is important that additional research and monitoring of Pacific lamprey in the Eel River is prioritized to address the key uncertainties outlined in Section 6.

Once discrete management actions are well-defined, where appropriate, we recommend that they be implemented, monitored, and refined by following an adaptive management process. Adaptive management is a systematic approach for improving resource management by learning from management outcomes (Williams et al. 2009, Figure 11). A specific process for adaptive management should be developed for each unique management action where applying the process is applicable. For example, following assessment of the Eel River pikeminnow population and its population-level impact on Pacific lamprey, WNRD may design and implement a program to actively suppress pikeminnow. This management action should be implemented through an adaptive management process tailored for the program, where, following initial implementation, effectiveness of the program is monitored, evaluated, and methods and level-of-effort are modified and refined to most efficiently meet the goals of the program. Numerous useful references are available for applying the adaptive management process, including a technical and applications guides developed by the U.S. Department of Interior for natural resources management problems (Williams et al. 2009, Williams and Brown 2012)

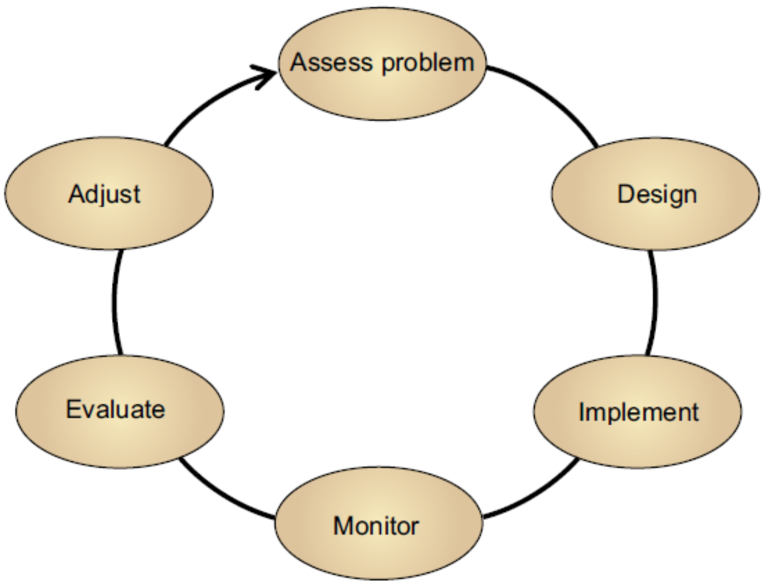

Figure 11: Diagram of the adaptive management plan process (from Williams et al. 2009).

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