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Monitoring Pacific Lamprey in Lower Eel River Basin: Pilot Surveys and Recommendations for Long-term Monitoring

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Cover photos: Upper left: conducting lamprey spawning surveys on Bull Creek. Lower left: mature Pacific lamprey observed during spawning surveys in the Van Duzen River. Upper right: immature adult Pacific lamprey measured during creel surveys. Lower right: sampling a quadrat during ammocoete index site surveys on the lower Eel River.

Table of Contents

ACKNOWLEDGMENTS..V

1 INTRODUCTION..1

1.1 Background and Need...1
1.2 Study Area...2

2 PILOT MONITORING..4

2.1 Ammocoete Surveys...4
2.1.1 Methods...4
2.1.2 Results...14
2.1.3 Discussion...25
2.2 Spawning Surveys...28
2.2.1 Methods...28
2.2.2 Results...31
2.2.3 Discussion...37
2.3 Creel Surveys...38
2.3.1 Methods...38
2.3.2 Results...41
2.3.3 Discussion...45

3 LONG-TERM MONITORING RECOMMENDATIONS...45

3.1 Monitoring Goals and Programmatic Considerations.................................45
3.2 Ammocoete Distribution...47
3.2.1 Site selection and spatial considerations.................................47
3.2.2 Timing and periodicity...48
3.2.3 Survey protocols...48
3.2.4 Metrics, analysis, and reporting...48
3.3 Ammocoete Relative Abundance...49
3.3.1 Site selection and spatial considerations.................................50
3.3.2 Timing and periodicity...51
3.3.3 Survey protocols...52
3.3.4 Metrics, analysis, and reporting...53
3.4 Spawning Adult Relative Abundance and Timing.................................54
3.4.1 Site selection and spatial considerations.................................55
3.4.2 Timing and periodicity...56
3.4.3 Survey protocols...56
3.4.4 Metrics, analysis, and reporting...57
3.5 Migratory Adult Relative Abundance and Timing.................................57
3.5.1 Site selection and spatial considerations.................................58
3.5.2 Timing and periodicity...58
3.5.3 Survey protocols...58
3.5.4 Metrics, analysis, and reporting...58
3.5.5 Opportunistic capture of migratory adults.................................59
3.6 Data Management and Quality Control...59

4 REFERENCES..60

Tables

Table 2-1. Streams in the Eel River basin study area where ammocoete distribution and habitat surveys were conducted in 2013–2014. 5
Table 2-2. Characteristics of ammocoete habitat categories used as a guideline for field classification of rearing habitat suitability. 7
Table 2-3. Variables evaluated for explaining observed variation in ammocoete density between sample quadrats. 13
Table 2-4. Sample effort and number of ammocoetes captured by taxon for ammocoete distribution surveys conducted in each stream in 2013–2014. 14
Table 2-5. Quantity of suitable ammocoete rearing habitat and LWD in survey reaches during 2013–2014 surveys. 17
Table 2-6. Comparison of monthly mean discharge during Water Year 2014 with the period of record for selected gages near the project study area. 19
Table 2-7. Minimum, maximum, and mean numbers of ammocoetes captured by species in 1-m^2 samples at index sites surveyed in 2014. 20
Table 2-8. Minimum, maximum, and mean lengths of Pacific lamprey ammocoetes captured at index sites surveyed in 2014. 21
Table 2-9. Results of power analyses estimating number of 1-m^2 samples needed to detect specified differences in density of Pacific lamprey ammocoetes at mainstem Eel River index sites using different t-tests. 23
Table 2-10. Results of power analyses estimating number of 1-m^2 samples needed to detect specified differences in density of Pacific lamprey ammocoetes at Van Duzen River index sites using different t-tests. 23
Table 2-11. Stream reaches in the Eel River basin study area where Pacific lamprey spawning surveys were conducted in 2014. 28
Table 2-12. Number of redds, spawning adults, and carcasses counted during bi-weekly surveys in 2014. 32
Table 2-13. Number of redds, spawning adults, and carcasses counted during peak surveys in 2014. 36
Table 2-14. Summary of eeling effort and Pacific lamprey capture at the mouth of the Eel River based on pilot creel surveys conducted in winter 2014. 42
Table 2-15. Summary of Pacific lamprey biological data collected during 2014 creel surveys at the Eel River mouth. 43
Table 2-16. Summary of responses to phone interview questions by regular Wiyot eelers. 44

Figures

Figure 1-1. Pilot survey study area in relation to Wiyot Ancestral Territory and other Eel River basin landmarks. 3
Figure 2-1. Locations of ammocoete distribution and index site surveys conducted in 2013–2014. 6
Figure 2-2. Example of an ammocoete index site sampled during 2014 pilot surveys: Looking downstream at Site ERI2. 10
Figure 2-3. Example index site diagram showing selected sample quadrats in the upper segment of Site EI1, located in an alcove on the lower Eel River 11
Figure 2-4. The 1-m^3 netted frame used for sampling ammocoetes in selected sample quadrats at index survey sites. 12
Figure 2-5. Relative abundance of ammocoetes >60 mm in 2013–2014 distribution survey reaches. 15

Figure 2-6. Length frequency of age-1 and older ammocoetes captured by species during 2013–2014 distribution surveys across all survey streams. 16
Figure 2-7. Suitable habitat area per length of channel surveyed for each survey reach during 2013–2014 distribution surveys. 17
Figure 2-8. Linear densities of instream and over-hanging LWD and percentage of suitable habitat patches that were associated with instream LWD for each survey reach during 2013–2014 distribution surveys. 18
Figure 2-9. Examples of dry or intermittent stream reaches encountered during summer 2014 ammocoete distribution surveys. 19
Figure 2-10. Mean density of ammocoetes ≥50 mm by species at each index site. 21
Figure 2-11. Percentage of Pacific lamprey ammocoetes captured by length class at each index site in the Eel River and Van Duzen River. 22
Figure 2-12. Number of ammocoetes captured in sample quadrats versus distance from the nearest bank at Eel and Van Duzen river index sites. 24
Figure 2-13. Locations of reaches where spawning surveys were conducted in 2014. 29
Figure 2-14. Number of Pacific lamprey redds observed in each reach of Lawrence Creek during bi-weekly surveys in 2014. 33
Figure 2-15. Number of Pacific lamprey redds observed in each reach of Bull Creek during bi-weekly surveys in 2014. 33
Figure 2-16. Percentage of Pacific lamprey redds still distinct, detectible, and not detectible versus time since first detection. 34
Figure 2-17. Number of Pacific lamprey redds counted in Bull and Lawrence creeks, water temperatures, and daily mean discharge during the survey period. 35
Figure 2-18. Linear density of redds from 2014 peak spawning surveys in the Eel River, Van Duzen River, Yager Creek, and South Fork Eel River survey reaches. 36
Figure 2-19. Number of eelers present, total eeling effort on dates surveyed, and discharge at the Scotia gage. 42
Figure 2-20. Number of Pacific lampreys captured or observed at the mouth of Eel River and catch-per-unit-effort on each survey date for which effort was expended. 43

Appendices

Appendix A. List of Streams for Ammocoete Surveys
Appendix B. Results of Statistical Analyses Informing Ammocoete Sampling at Index Sites
Appendix C. Pacific Lamprey Long-term Monitoring Program Summary Table

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1 INTRODUCTION

1.1 Background and Need

The Pacific lamprey, *Entosphenus tridentatus*, is an ecologically and culturally important species in the Northwest (Close et al. 2002, Petersen-Lewis 2009, Luzier et al. 2011) and it has particular significance to the Wiyot Tribe in Northern California. Available evidence suggests that the species' population and range have declined substantially from historical levels both regionally (Moser and Close 2003, Nawa 2003, Moyle et al. 2009, Luzier et al. 2011) and in the Eel River basin (Stillwater Sciences 2010, Stillwater Sciences 2014a), which received its English name due to the fact that it once contained large numbers of Pacific lampreys (commonly referred to as eels, or *gou'daw* in the Wiyot language).

In response to declining Pacific lamprey populations and lack of information, the Wiyot Tribe and Stillwater Sciences have implemented a program to study and restore the species in the Eel River basin. After performing an initial review of information and identifying key data gaps and potential threats to the species (Stillwater Sciences 2010), we developed a life-history-based conceptual model to use as a framework for identifying factors most likely limiting the species in the basin (Stillwater 2014). These documents highlighted the lack of information on life history and distribution of the species and pointed toward the need for more systematic collection of population data—both to monitor temporal trends in distribution and abundance, and to inform our growing understanding of basic biology and limiting factors in the basin.

Accordingly, herein we present a strategy for long-term monitoring of Pacific lamprey in the Eel River basin. The primary goal of the Wiyot Tribe's Pacific lamprey monitoring program is to monitor trends in abundance and distribution of the species within the lower Eel River basin in support of effective management, conservation, and restoration. Collection of baseline information on distribution and life history of the species in the study area and testing and refining monitoring methodologies are imperative first steps in designing and implementing a monitoring program. Thus, in 2013–2014 we conducted pilot ammocoete and spawning surveys in selected portions of the lower Eel River basin to better understand patterns in distribution and spawning and test methods. Additionally, we designed and implemented a systematic and repeatable creel survey of lamprey harvest that will be used as an indicator of annual adult run size in the Eel River. Results of these pilot surveys are presented in Section 2.

Importantly, pilot surveys were used to inform development of sampling strategies, refinement of field protocols, and selection of survey sites for each element of the long-term monitoring program. Section 3 presents a systematic multi-life-stage framework for monitoring Pacific lamprey, including the following considerations for each monitoring element: spatial scale, numbers, and locations of survey sites; sample periodicity and seasonal timing; effort required; and monitoring metrics.

The Wiyot Tribe Natural Resources Department (WNRD) conducted fieldwork for this project with training and technical assistance provided by Stillwater Sciences. Data analysis and reporting for 2014 pilot surveys and development of the long-term monitoring program was led by Stillwater Sciences with input and editorial review from WNRD.

1.2 Study Area

The geographic focus of long-term monitoring of Pacific lamprey by the Wiyot Tribe is Wiyot ancestral territory and adjacent portions of the lower Eel, Van Duzen, and South Fork Eel watersheds that are of interest to the Tribe and close enough to the tribal office to regularly monitor. This geographic scope recognizes the logistical and budgetary realities of monitoring a species in a large river system. We anticipate that development and implementation of a Pacific lamprey monitoring program for lower portions of the Eel basin will encourage other Tribal and agency entities to implement similar programs in other parts of the basin, ideally in a manner consistent with and coordinated with this program.

The study area for 2013–2014 pilot ammocoete surveys included the lower Eel River upstream to the South Fork Eel River confluence, the Van Duzen River upstream to and including Grizzly Creek, and Bull Creek, a major tributary to the lower South Fork Eel River (Figure 1-1). The study area for 2014 spawning surveys included the ammocoete study area plus an additional 4 miles of the mainstem Van Duzen River and approximately 40 miles of the mainstem South Fork Eel upstream to the East Branch of the South Fork Eel River. Stillwater Sciences (2014a) provides more information on the geographic, climatic, and land-use characteristics of the Eel River basin.

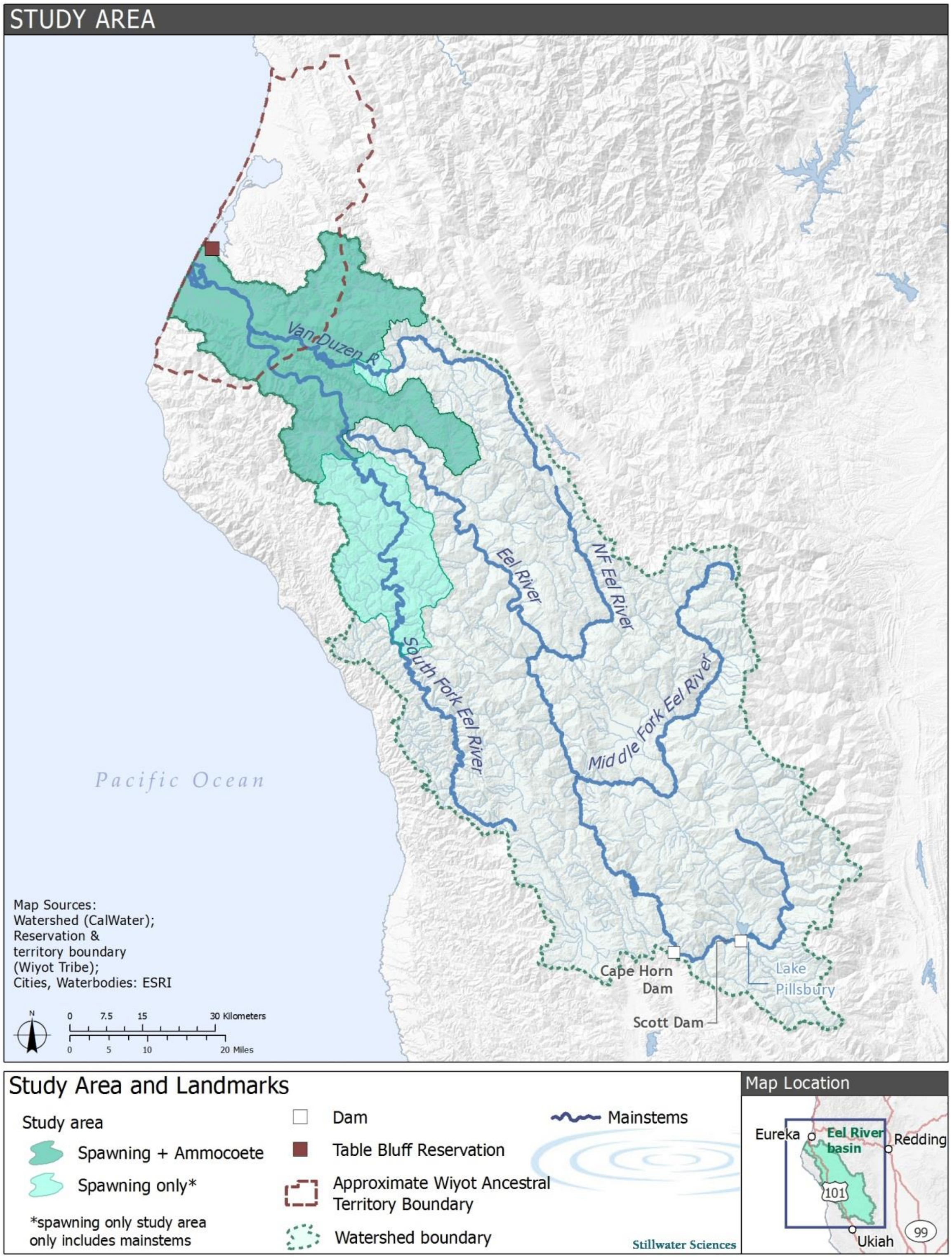


Figure 1-1. Pilot survey study area in relation to Wiyot Ancestral Territory and other Eel River basin landmarks.

2 PILOT MONITORING

2.1 Ammocoete Surveys

Ammocoete surveys conducted during 2013–2014 pilot monitoring consisted of distribution and habitat surveys conducted in wadeable streams and relative abundance surveys at index sites in unwadeable streams. The primary objectives of these surveys were: (1) expand understanding of Pacific lamprey distribution and basic biology within the study area, (2) test and refine methodologies for monitoring distribution and abundance of the ammocoete population, and (3) inform selection of index sites that will be revisited periodically as part of long-term monitoring of the species in the Eel River study area. Methods and results of these surveys are presented below.

2.1.1 Methods

2.1.1.1 Distribution surveys

Distribution surveys were designed to facilitate efficient detection of ammocoete presence, while also allowing for collection of data informing relative abundance and habitat availability within survey reaches.

Study reaches for distribution surveys were selected from an initial list of 129 streams within the study area listed in the Geographic Names Information System (GNIS). Thirty-two of these streams were excluded from consideration due to having contributing drainage areas <2 km^2 or drainage areas <5 km^2 and channel gradients predominately >8%. However, two streams with drainage area <2 km^2, Little Palmer and Finch creeks were kept on the list due to their low gradient and proximity to the Table Bluff Reservation. Channel gradient and drainage area for stream reaches in the study area were determined from Geographic Information Systems (GIS) and high-resolution channel network attributed with these features as described in Stillwater Sciences (2014b). The remaining 97 streams constituted the sampling frame for distribution surveys in the study area (Appendix A). Streams for conducting pilot distribution surveys were prioritized by WNRD based on proximity to the Table Bluff Reservation, stream size (drainage area generally >10 km^2), channel gradient (lower gradient streams), and general accessibility and convenience (e.g., proximity to other survey streams). Additionally, streams or reaches where Pacific lampreys were recently definitively detected (Stillwater Sciences 2014a) were not surveyed.

Systematic ammocoete distribution surveys were conducted in thirteen streams in the study area between December 2013 and September 2014 (Table 2-1, Figure 2-1). Within a stream, standard distribution surveys generally began at the confluence with a larger stream and continued upstream. In Root Creek, only habitat surveys were conducted because the stream was predominately dry and there was no suitable wetted habitat during the survey. Additionally, numerous small to moderate sized streams in the study area were visited, but could not be surveyed due to the severe drought in the region, which led to lack of water and/or presence of high densities of salmonids trapped in small, isolated pools. Opportunistic sampling was conducted at a single site on Lawrence Creek near the mouth of Bell Creek to help inform upper distribution in the stream.

Table 2-1. Streams in the Eel River basin study area where ammocoete distribution and habitat surveys were conducted in 2013–2014.

Stream	Reach ID[1]	Tributary to	Sub-basin	Stream drainage area (km^2)	Survey date
Bear Cr	001	Eel River	Lower Eel	21.9	12/18/2013
Price Cr	002	Eel River	Lower Eel	34.0	1/15/2014
Strongs Cr	003	Eel River	Lower Eel	43.8	1/21/2014
Howe Cr	004	Eel River	Lower Eel	28.3	1/28/2014
Rohner Cr	005	Strongs Cr	Lower Eel	11.8	2/4/2014
Atwell Cr	006	Howe Cr	Lower Eel	11.1	2/6/2014
Booths Run	007	Lawrence Cr	Van Duzen	15.4	7/15/2014
Bell Cr	008	Lawrence Cr	Van Duzen	11.6	7/15/2014
Shaw Cr	009	Lawrence Cr	Van Duzen	13.6	7/22/2014
Blanton Cr	010	Yager Cr	Van Duzen	8.2	7/22/2014
Cuneo Cr	011	Bull Cr	SF Eel	11.3	7/28/2014
SF Yager Cr	012	Yager Cr	Van Duzen	27.8	7/30/2014
Root Cr[2]	013	Van Duzen	Van Duzen	16.6	9/11/2014
Grizzly Cr	014	Van Duzen	Van Duzen	49.0	9/11/2014
Lawrence Cr[3]	n/a	Van Duzen	Van Duzen	43.0	7/15/2014

1 Reach ID is provided here to facilitate locating reaches in Figure 2-1.
2 Electrofishing was not conducted in Root Cr because the stream was predominately dry and there was no suitable wetted habitat.
3 Sampled opportunistically at the mouth of Bell Creek. Drainage area listed is for this location.

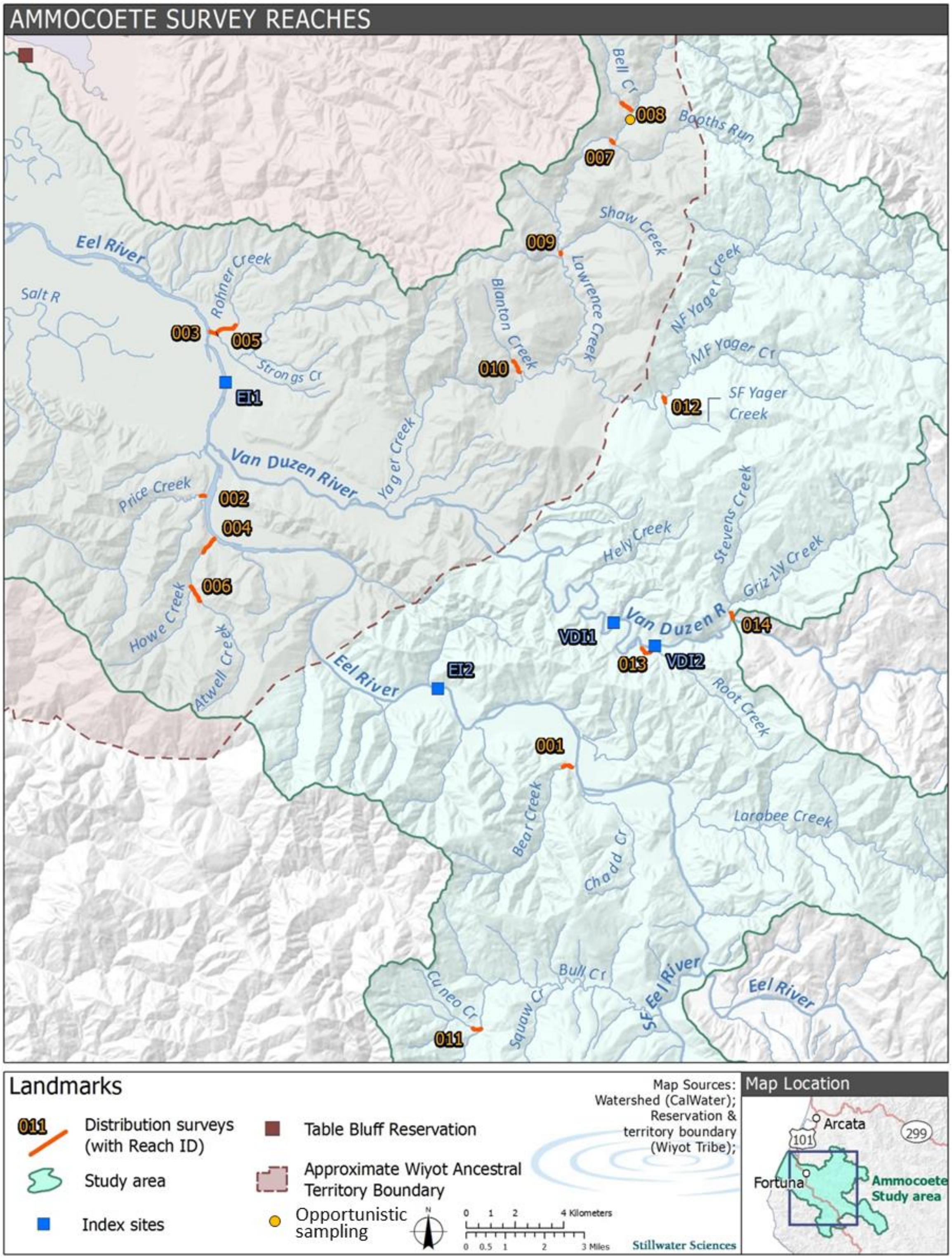


Figure 2-1. Locations of ammocoete distribution and index site surveys conducted in 2013–2014.

Distribution surveys for each stream reach were carried out by systematically sampling all suitable ammocoete habitat (see Table 2-2) in 100-m channel segments (measured along the thalweg with a laser range finder or tape), typically starting at a stream's confluence and continuing upstream until one of the following occurred:

- Pacific lampreys were definitively documented after surveying at least one 100-m channel segment.
- At least ten 100-m segments (1,000 m) of channel were surveyed and no Pacific lampreys were found.
- Approximately 10 non-adjacent and highly suitable (Type I) ammocoete habitat patches, each with an area greater than 1 m^2 (10.8 ft^2), were sampled and no Pacific lampreys were found—and at least three 100-m segments of stream were surveyed.
- Access was limited due to safety concerns or private property.

For each 100-m stream segment, ammocoete and habitat data were collected as described below. Ammocoetes were sampled using an ETS AbP-2 backpack electrofisher designed to capture lampreys burrowed in stream substrates. All suitable (see Table 2-2) ammocoete habitat patches encountered (including those in alcoves, side channels, and other off-channel features) that were larger than 1 m^2 were sampled. Suitable habitat patches were visually identified and categorized as either Type I (preferred) or Type II (acceptable) based on dominant substrate characteristics and particle sizes. Table 2-2 was used to assist with objective identification and categorization of habitat type. Table 2-2 generally follows descriptions of rearing habitat types outlined by others (e.g., Slade et al. 2003, Fodale et al. 2003), but attempts to describe substrate characteristics of each type more precisely based on recent descriptions of ammocoete habitat preference (e.g., Torgersen and Close 2004, Stone and Barndt 2005, Claire 2004). In stream segments containing no or few suitable habitat patches >1 m^2, opportunistic electrofishing of smaller patches or patches with borderline suitability (e.g., clay or gravel substrates) was carried out to help accomplish the primary objective of detecting lamprey presence.

Table 2-2. Characteristics of ammocoete habitat categories used as a guideline for field classification of rearing habitat suitability.

Rearing habitat type	Dominant substrate	Particle size range (mm)[1]	Notes on classification
Type I/ Preferred	Silt with or without organic matter	0.004–0.062	Finer-grained sediment (clays) not suitable unless loosely packed and mixed with substantial fraction of organic matter.
	Fine to medium grain sand with substantial fraction of silt or organic matter	0.063–0.50	Substrates dominated by coarser-grained sands (<2 mm) may be categorized as Type I only if they contain a substantial fraction of organic matter and silts.

Rearing habitat type	Dominant substrate	Particle size range (mm)[1]	Notes on classification
Type II/ Acceptable	Medium grain to coarse sand with zero to very little silt or organic matter	0.25–2.0	Considered acceptable if mixed with some gravel and small cobble substrates if other habitat characteristics are also highly suitable. Not considered acceptable if hard-packed.
	Fine gravel with a substantial fraction of fine sand, silt, or organic matter	2.0–8.0	Substrates dominated by medium gravel (8–16 mm) may be categorized as Type II if they are loosely packed and contain substantial fraction of finer substrates or organic matter.
Type III/ Not Acceptable	Clay sediments	<0.004	Clay sediments are generally too compacted for burrowing. Coarse-grained clays may be acceptable if they are loosely packed and contain significant fractions of silt and/or organic matter and other habitat characteristics are also suitable.
	Medium to coarse gravel	8–64	Generally considered not acceptable. Ammocoetes have been documented in gravel substrates, but they are considered marginal habitat.
	Small cobble and larger including bedrock	>64	Ammocoetes have been documented in cobble substrates, but they are considered marginal habitat.

[1] Sizes based on the Wentworth scale (Wentworth 1922).

Electrofishing was conducted by a field crew consisting of an operator and one or two netters. Each suitable habitat patch was systematically sampled with a thorough, single pass, at a rate of approximately 90 s per m^2 of suitable habitat. Direct current was delivered using the primary slow-pulse channel at three pulses/s second to induce ammocoete emergence from substrate. When necessary, the secondary fast-pulse electrofishing channel, with a direct current of 30 pulses/s, was applied to aid in capture of ammocoetes that emerged from the substrate by stunning them. A 25% duty cycle and 3:1 burst-pulse train cycle were applied and peak output voltage for both channels was typically 125 V. Sampling effort for each habitat patch and 100-m stream segment was recorded as seconds of time slow-pulse current was applied, using the built-in timer on the AbP-2 electrofisher.

Length and average width of each Type I and Type II habitat patch were measured with a stadia rod or tape and used to estimate total habitat area (and thus the sample time required). Only substrate that was wetted during the date of the survey was measured and sampled. The entire area of suitable habitat patches smaller than 10 m^2 (108 ft^2) were sampled. However, it was necessary to sub-sample larger patches to ensure sufficient time remained to survey an adequate length of channel for documenting presence of Pacific lamprey. For patches larger than 10 m^2 (108 ft^2) and smaller than 30 m^2 (323 ft^2), a subsample of 10 m^2 was conducted. For patches larger than 30 m^2, 33% of the patch area was subsampled. Prior to beginning subsampling, approximate boundaries of a sub-sample area representative of the larger patch were delineated. This area was sampled at the same rate of 90s per m^2 of habitat.

When encountering a significant side-channel branching off the 100-m survey segment, it was sampled following completion of the main channel segment. Side channels were essentially treated as additional survey segments and sampled in their entirety using the same methods as main channels. Side channel length was estimated using a laser range finder or tape.

After electrofishing each 100-m survey segment, all captured lampreys were anesthetized, measured to the nearest 1 mm, identified to genus (either *Entosphenus* or *Lampetra*) where possible (typically individuals >60 mm) by examining caudal fin and ventral pigmentation (Goodman et al. 2009, Reid 2012), and categorized as one of the following life stages: ammocoetes, eyed-ammocoetes ("transformers"), macrophthalmia, or adult. After recovering from anesthesia, all captured individuals were released within the 100-m segment in which they were captured.

In addition to data on captured lampreys, we recorded the following information for each 100-m survey segment:

- GPS coordinates at segment start and end points.
- Maximum substrate depth of each habitat patch sampled.
- Number of qualifying large wood (LWD) pieces in the survey segment that were instream (touching water or the active channel) and overhanging (perched above the active channel). Qualifying LWD was defined as a piece of wood either >15 cm in diameter and 2 m long or a root wad with a cut end >30 cm in diameter with no minimum length.
- Whether each habitat patch was associated with (adjacent to and apparently created by) one or more pieces of large wood.
- A minimum of two bankfull and wetted width measurements at representative locations within the survey segment.
- Qualitative ratings of relative abundance of suitable Pacific lamprey spawning habitat to aid in selection of potential spawning survey reaches (Section 2.2).
- Photographs looking upstream and downstream from the start, mid, and end points of the segment and of other noteworthy features such as large Type I habitat patches, side channels, large wood jams, or significant bank erosion.

2.1.1.2 Index site relative abundance surveys

The purpose of the pilot index site surveys was to test sampling protocols for characterizing relative abundance of ammocoetes in large patches of high quality habitat within unwadeable streams. The ultimate goal of index site surveys is to evaluate trends in relative abundance at these sites over time as part of long-term monitoring. The pilot surveys were designed to estimate relative abundance of ammocoetes (measured as fish/m^2) while also informing how many samples are required to detect changes in abundance at each site over time. A secondary aim of these pilot surveys was to determine if lamprey density within a site was related to habitat variables such as distance from shore, water depth, substrate depth, or presence of aquatic vegetation, dead organic matter, or algal mats in the sample quadrat. Understanding these relationships contributed to the design of a sampling strategy that more accurately estimates density at each site.

Field methods

In early fall 2014, pilot ammocoete electrofishing surveys were conducted at four index sites in the study area, two in the lower Eel River and two in the Van Duzen River (Figure 2-1). We selected sites that had easy access and a relatively large (wetted area greater than approximately 150 m^2) and contiguous area of Type I habitat (e.g., Figure 2-2).

Figure 2-2. Example of an ammocoete index site sampled during 2014 pilot surveys: Looking downstream at Site ERI2 (Eel River near Stafford).

When arriving at each index site, the site was diagrammed to scale on gridded paper using a stadia rod and 100-m measuring tape to assist with selection of areas to be sampled by electrofishing (e.g., Figure 2-3). These diagrams included:

- The wetted boundary of Type I habitat patch to be sampled,
- The wetted boundary of nearest stream bank, and
- The boundary of suitable substrate that was contiguous with the patch to be sampled but dry on the sample date.

If an edge of patch was too deep for effective sampling with the backpack electrofisher (>1 m), the maximum depth boundary was drawn and the area of suitable habitat too deep for sampling was estimated visually and recorded.

After diagraming the patch boundaries, the patch was evenly divided into lower, middle, and upper segments based on length of the patch from downstream to upstream. Next, ten 1 m^2 sample quadrats were selected (as described below) within each of the three segments for a total area of 30 m^2 to be sampled at each site. Sample quadrats were evenly spaced, separated by at least 1 m, in a zig-zag pattern from downstream to upstream and from the bank edge to the thalweg edge of the patch to capture variation in depth and distance from bank at the site (Figure 2-3).

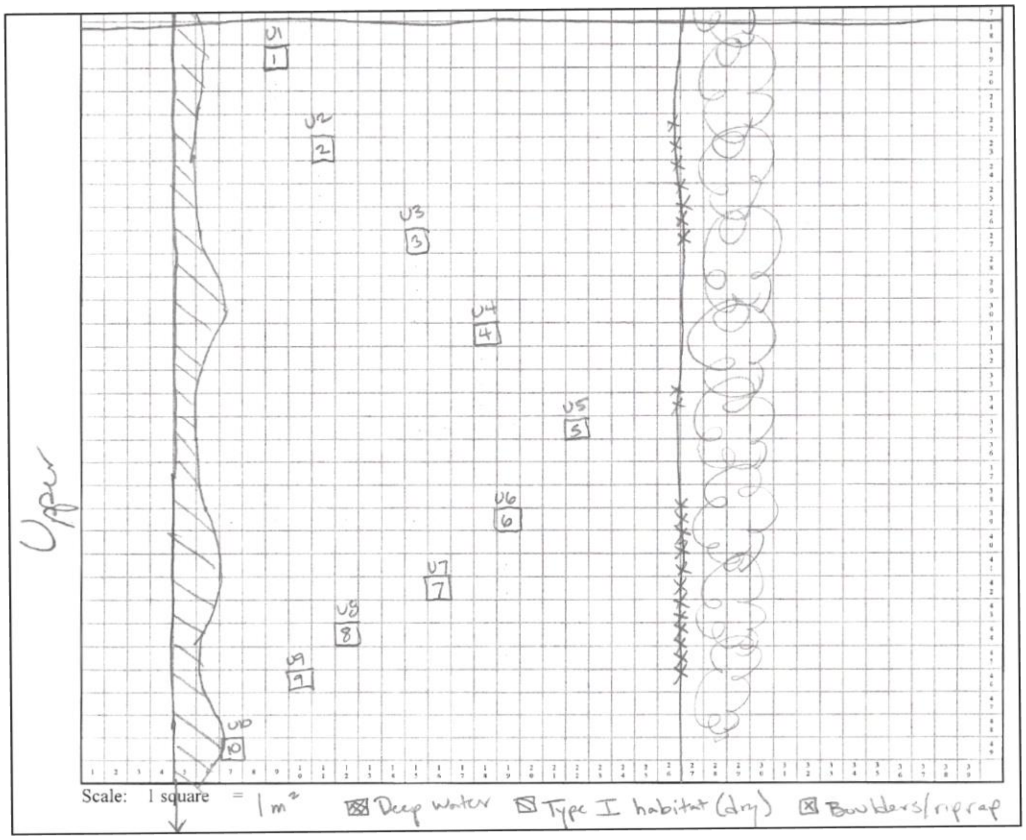


Figure 2-3. Example index site diagram showing selected sample quadrats in the upper segment of Site EI1, located in an alcove on the lower Eel River (note: lower and middle segments not shown).

After selecting locations of sample quadrats, each quadrat was sampled with a single 90s pass (based on slow-pulse timer) using an ETS AbP-2 backpack electrofisher with the settings described above. Quadrats were sampled in the downstream to upstream direction. A one m^3 netted frame covered with a fine-meshed (0.6 mm) polyester material on the sides was placed on each sample quadrat to aid in capture of ammocoetes (Figure 2-4). An attempt was made to capture all lampreys that clearly originated from the substrate within the sample quadrat. In cases where there were large numbers of young-of-the-year ammocoetes (<25 mm), capture of larger individuals was prioritized. The number of ammocoetes seen emerging from the substrate but not captured was estimated and tallied. Captured ammocoetes from each quadrat were placed in separate 5-gallon buckets for identification and measurement using the methods described above for distribution surveys. After recovering from anesthesia, all captured individuals were released near the area they were captured in, but well downstream of subsequent sample quadrats to avoid re-capture.

Figure 2-4. The 1-m^3 netted frame used for sampling ammocoetes in selected sample quadrats at index survey sites.

The following information was measured and recorded for each 1-m^2 sample quadrat:

- Distance to bank (water's edge) from center of the sample quadrat.
- Distance from downstream end of index site.
- Water depth measured at center of frame.
- Maximum sediment depth measured by inserting a rebar stake into the substrate and recorded as <10 cm, 10–30 cm, or >30 cm. Sediment depth was measured following electrofishing to avoid disturbing burrowed ammocoetes.
- Presence of live aquatic vegetation, dead organic matter (e.g., leaves, small sticks, etc.), and algal mats (e.g., genus *Cladophera*).

Finally, site photographs were taken and GPS coordinates and notes were recorded for each index site.

Data analysis

Sample effort required

We applied conventional power analyses run through the statistical programming language and software environment R to evaluate the number of 1-m^2 samples required to detect: (a) differences in mean density of Pacific lamprey ammocoetes within an index site across years using a *paired t-test*, and (b) differences in densities between sites within a year using a *two-sample t-test*. The analyses were based on variance in observed densities and used 95% confidence and 80% power.

These analyses focused on Pacific lamprey density, since it is the primary response variable that is the objective of the monitoring program. Ammocoetes <50 mm were excluded from these analyses due to inconsistency in how they were captured and processed between sites, since they could not be reliably identified to species, and because larger and older individuals are presumed to be a more reliable indicator of population status due to expected high variability in distribution and survival of the younger age-classes (particularly young-of-the-year).

Habitat relationships

Various statistical analyses were conducted to evaluate the relationships between ammocoete density and the variables listed in Table 2-3. Analyses of habitat relationships again excluded ammocoetes <50 mm, but lumped Pacific lamprey with *Lampetra* and unidentified ammocoetes, under the assumption that lamprey species are essentially ecologically identical as ammocoetes.

Table 2-3. Variables evaluated for explaining observed variation in ammocoete density between sample quadrats.

Variable code	Description
site	index sites (EI1, EI2, VDI1, and VDI2)
dist.us	distance of sample quadrat from downstream end of index site
dist.bank	distance of sample quadrat from nearest bank
water.depth	water depth measured at center of sample quadrat
substrate.depth	maximum substrate depth in sample quadrat (<10 cm, 10–30 cm, or > 30 cm)
vegLive	presence of live vegetation
organicDead	presence of dead organic matter
algalMat	presence of algal mats

Initially, full ANOVA models were run with data collected at both the Eel River sites and the Van Duzen River sites to evaluate which covariates might explain observed variability in ammocoete density between sampled quadrats. Then a series of linear regression models containing each covariate individually (in addition to "*site*") were run as a separate means of evaluating potential predictors of ammocoete density. A matrix of correlation coefficients (r) was also generated to explore how the various covariates were related to ammocoete densities and each other at sites in each river.

Finally, the relationships between ammocoete density and variables of interest (i.e., strongly related to density) were explored further using a non-parametric regression technique based on kernel smoothing. Specifically, using data for each site, ammocoete density was treated as a Poisson variable whose expected value is of the form $1/(1+\exp(-f(x)))$, where x is the habitat variable of interest and $f(x)$ is a non-parametric function estimated by kernel smoothing (smoothing parameter h = 2). The analysis was carried out in R, using the function *sm.poisson* from the *sm* library of Bowman and Azzalini (1997). Results of statistical analyses are summarized in Section 2.1.2.2, and more detailed results are presented in Appendix B.

2.1.2 Results

2.1.2.1 Distribution surveys

Distribution, effort, and relative abundance

Electrofishing was conducted in 13 of the 14 streams systematically surveyed for distribution. No electrofishing was conducted in Root Creek because the channel was dry for most of the survey reach and no suitable wetted habitat was located. Lamprey ammocoetes were detected in 9 of the 13 streams electrofished (Table 2-3). Both Pacific lamprey (*Entosphenus*) and unknown *Lampetra* species were detected in 5 of the 13 streams sampled; although both genera were only found together in one stream, Price Creek. Pacific lamprey ammocoetes were also detected in Lawrence Creek near the mouth of Bell Creek during opportunistic electrofishing to help understand upper distribution in the watershed.

Overall, only 10 definitive Pacific lamprey ammocoetes were captured across the 7,200 m of channel surveyed, compared with 104 *Lampetra* ammocoetes and 30 that could not be identified (Table 2-4). No eyed Pacific lamprey (partly transformed ammocoetes or macrophthalmia) were captured during distribution surveys, but several *Lampetra* classified as partially transformed or immature adults were captured in Price, Rohner, and Atwell creeks.

Length of channel surveyed for lamprey distribution in each stream varied between 100 and 1,090 meters, depending on how quickly the criteria for ending a survey were met. Electrofishing effort (time slow-pulse current was applied), for each stream varied from approximately 3 to 93 minutes, depending on length of the survey reach and the area of suitable habitat present. Excluding two study streams that were high and low outliers, electrofishing rate (seconds of slow-pulse current per m^2 of suitable habitat sampled) ranged from 81 to 99 s/m^2 and averaged 90.0 s/m^2, the target rate. For Grizzly Creek, electrofishing rate was only 29 s/m^2 due to early detection of Pacific lamprey and the presence of stranded salmonids, which precluded further sampling. Electrofishing rate for Booths Run was 199 s/m^2 due to the relatively small area of suitable habitat present in the study reach and additional effort expended to detect ammocoetes there.

Table 2-4. Sample effort and number of ammocoetes captured by taxon for ammocoete distribution surveys conducted in each stream in 2013-2014.

Stream	Length of channel surveyed (m)	Area of suitable habitat sampled (m^2)[1]	E-fishing effort (min)[2]	Number of ammocoetes captured by taxon[3,4]			
				ET	LS	UK[5]	Total
Bear Cr	400	33.5	47.9	0	0	0	0
Price Cr	200	16.5	30.0	2	19[6]	1	22
Strongs Cr	300	67.1	93.3	0	8	1	9
Howe Cr	1,090	0.0	19.3	0	2	0	2
Rohner Cr	1,000	16.8	49.2	0	24[6]	10	34
Atwell Cr	800	28.5	78.0	0	51[6]	15	66
Booths Run	100	0.8	2.8	3	0	1	4
Bell Cr	620	19.9	32.8	0	0	0	0
Shaw Cr	100	9.3	13.5	3	0	1	4
Blanton Cr	700	11.1	17.0	0	0	0	0
Cuneo Cr	400	0.9	1.5	0	0	0	0
SF Yager Cr	300	11.1	22.2	1	0	0	1

Stream	Length of channel surveyed (m)	Area of suitable habitat sampled (m²)[1]	E-fishing effort (min)[2]	Number of ammocoetes captured by taxon[3,4]			
				ET	LS	UK[5]	Total
Root Cr	900	0.0	0.0	-	-	-	-
Grizzly Cr	300	12.2	5.9	1	0	1	2
Total	**7,210**	**227.8**	**413**	**10**	**104**	**30**	**144**

1 Area of Type I and Type II habitat patches >1 m^2 sampled in survey reach.
2 Includes time slow-pulse current was applied within designated Type I and Type II habitat patches >1 m^2 and opportunistic electrofishing of smaller patches or those with borderline suitability.
3 Not including age-0 ammocoetes (>25 mm), which were detected in Rohner and Atwell creeks but not captured.
4 ET = *Entosphenus* or Pacific lamprey, LS = *Lampetra* species, UK = unknown species.
5 Includes individuals that were observed during surveys but not captured.
6 Includes 11 eyed individuals that were classified as either partially transformed ammocoetes or immature adults.

In survey reaches where ammocoetes were detected, linear densities (fish per unit length of stream) of all species combined ranged from 0.2 fish/100 m in Howe Creek to 11.0 fish/100 m in Price Creek (Figure 2-5). *Entosphenus* densities were highest in the Shaw Creek and Booths Run survey reaches, followed by Price Creek. The lower electrofishing rate applied in Grizzly Creek likely resulted in an under estimate of linear density relative to the other survey reaches. *Lampetra* densities were highest in Price Creek, followed by Atwell, Strongs, and Rohner creeks. For the reasons discussed in Section 2.1.3, these coarse estimates of relative abundance should be viewed cautiously.

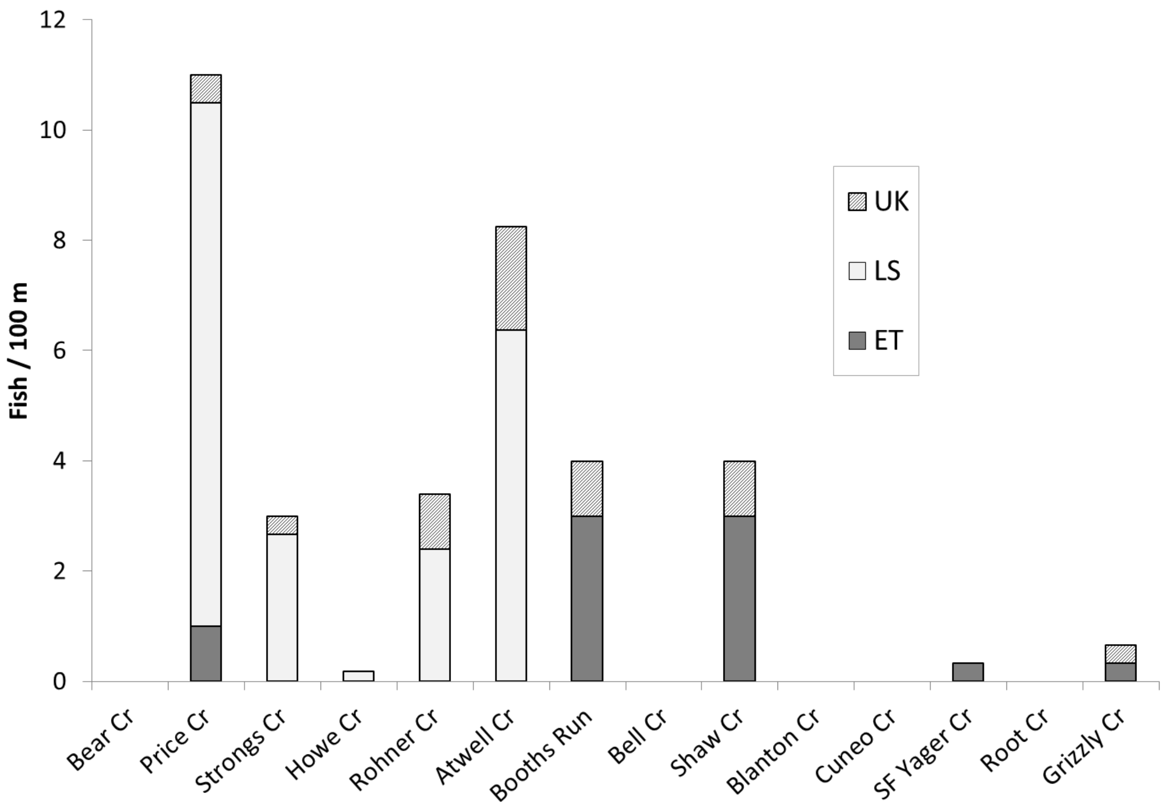


Figure 2-5. Relative abundance of ammocoetes >60 mm (number captured per 100m of channel surveyed) in 2013–2014 distribution survey reaches. ET = *Entosphenus* or Pacific lamprey, LS = *Lampetra* species, UK = unknown species.

Excluding age-0 ammocoetes (defined as <25 mm), all ammocoetes captured were larger than 60 mm (Figure 2-6). Length of the 10 Pacific lamprey ammocoetes captured during distribution surveys ranged from 76–161 mm and averaged 125.2 mm (only 1 individual was <100 mm). Length of the 93 *Lampetra* ammocoetes ranged from 64–164 mm, and averaged 110.6 mm. The lack of individuals of both species between approximately 25–60 mm suggests potential loss of one or more year classes or size-specific differences in capture efficiency or behavior. However, differences in capture efficiency are unlikely to explain the total absence of smaller size classes observed here.

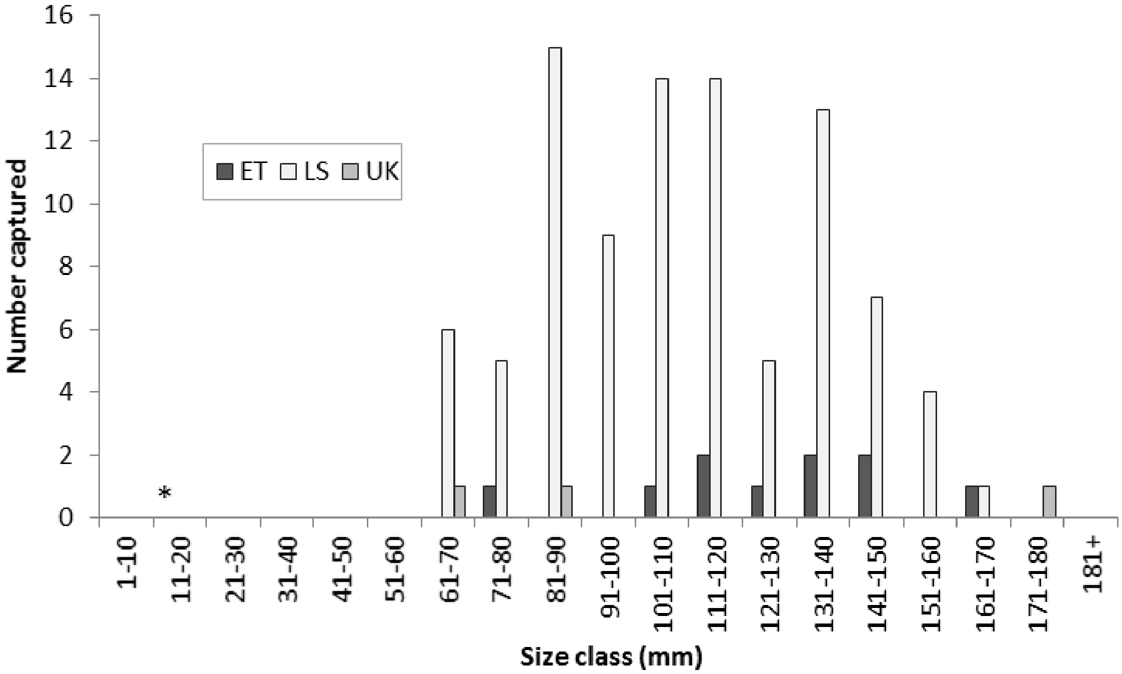


Figure 2-6. Length frequency of age-1 and older ammocoetes captured by species during 2013-2014 distribution surveys across all survey streams. (*Approximately 75 age-0 ammocoetes (<25 mm) were observed but not captured.)

Habitat quantity and quality

Number of suitable ammocoete rearing habitat patches and total suitable habitat area varied substantially between study reaches (Table 2-5). Suitable habitat area per unit length of stream surveyed was by far the highest in the Strongs Creek reach, which had nearly 45 m^2 of suitable habitat per 100 m (consisting entirely of Type I) (Figure 2-7). The survey reaches with the next highest density of habitat—Bear, Price, and Shaw creeks—had between 8 m^2 and 10 m^2 of suitable habitat per 100 m. No suitable habitat patches greater than 1 m^2 were documented in the Howe Creek survey reach; although several smaller patches with borderline suitability were electrofished during the survey. No suitable habitat patches were documented in Root Creek due primarily to lack of water in the survey reach.

Table 2-5. Quantity of suitable ammocoete rearing habitat (Type I and Type II) and LWD in survey reaches during 2013-2014 surveys.

Stream	Number of suitable habitat patches[1]			Area of suitable habitat in survey reach (m^2)[2,3]			LWD pieces in survey reach[4]		% of habitat patches associated with instream LWD
	Type I	Type II	Total	Type I	Type II	Total	In-stream	Over-hanging	
Bear Cr	6	5	11	24.0	9.5	33.5	54	0	82%
Price Cr	2	3	5	5.5	11.0	16.5	5	8	0%
Strongs Cr	10	0	10	132.6	0.0	132.6	48	1	40%
Howe Cr	0	0	0	0.0	0.0	0.0	46	18	-
Rohner Cr	0	8	8	0.0	16.8	16.8	48	13	13%
Atwell Cr	10	2	12	33.0	1.9	34.8	86	45	67%
Booths Run	0	1	1	0.0	0.8	0.8	15	5	100%
Bell Cr	10	0	10	19.9	0.0	19.9	83	50	40%
Shaw Cr	1	1	2	8.4	0.9	9.3	22	2	100%
Blanton Cr	3	4	7	5.0	6.0	11.1	228	114	86%
Cuneo Cr	1	0	1	0.9	0.0	0.9	21	7	0%
SF Yager Cr	1	1	2	1.9	9.3	11.1	30	1	50%
Root Cr	0	0	0	0.0	0.0	0.0	175	3	-
Grizzly Cr	2	0	2	18.5	0.0	18.5	28	3	100%

1 Only patches that were wetted and >1 m^2 were counted.
2 Only includes habitat from patches that were wetted and >1 m^2.
3 For some streams, the entire habitat area was not sampled due to subsampling of patches >10 m^2.
4 LWD was defined as a piece of wood either >15 cm in diameter and 2 m long or a root wad with a cut end >30 cm in diameter with no minimum length.

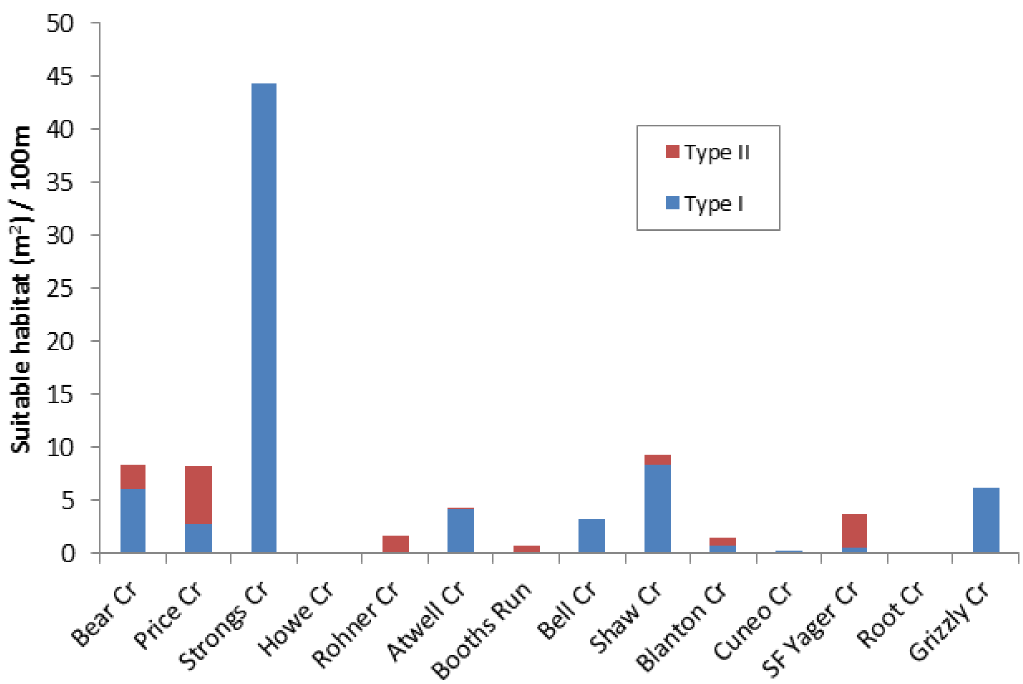


Figure 2-7. Suitable habitat area per length of channel surveyed for each survey reach during 2013-2014 distribution surveys.

The quantity of LWD varied considerably amongst survey reaches, with highest linear densities (pieces/100 m) observed in Blanton Creek and lowest densities in Price, Howe, Rohner, and Cuneo creeks (Figure 2-8). In most, but not all, reaches a relatively high percentage of the designated suitable habitat patches were associated with instream LWD (Figure 2-8). However, linear density of suitable habitat area was not correlated with linear density of instream LWD in survey reaches ($r^2 = 0.012$). Within survey reaches in which ammocoetes were detected, there was also not a significant correlation between ammocoete linear density and LWD linear density ($r^2 = 0.072$).

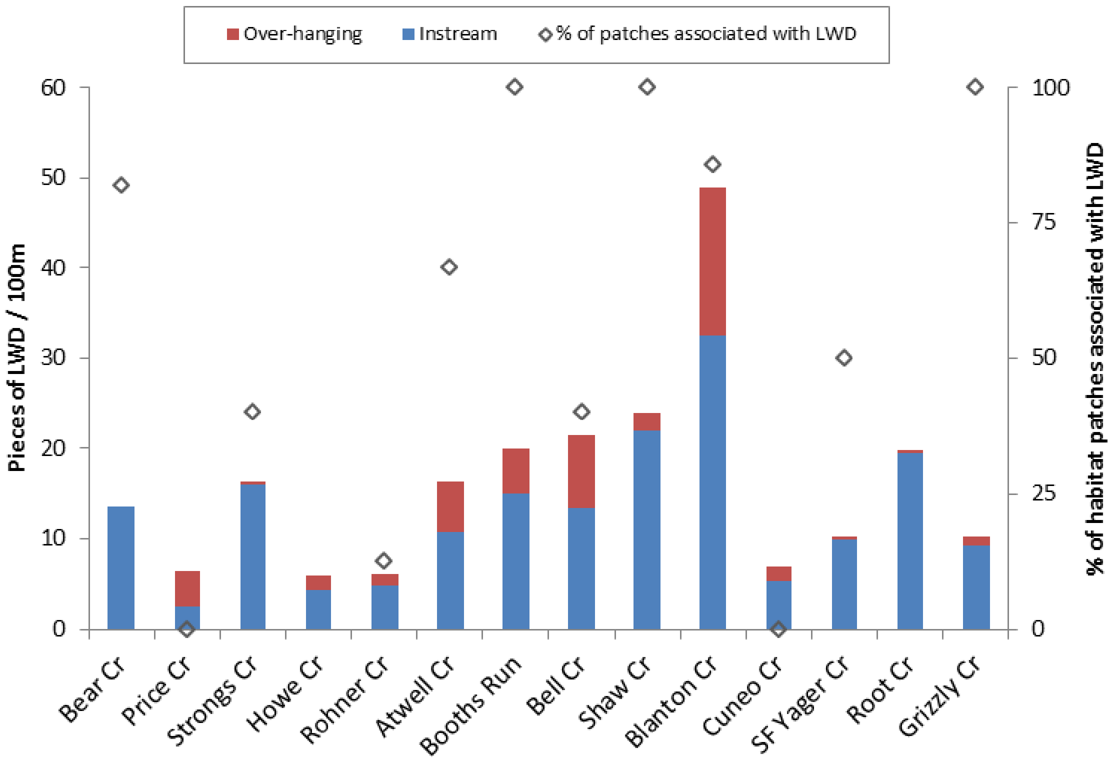


Figure 2-8. Linear densities of instream and over-hanging LWD (pieces per 100 m of channel surveyed) and percentage of suitable habitat patches that were associated with instream LWD for each survey reach during 2013-2014 distribution surveys.

Water temperature and stream flow

Water temperatures measured at the beginning of each distribution survey (in mid to late morning) ranged from 4.0–8.5°C during winter surveys and from 12.5–17.5°C during summer surveys (refer to Table 2-1 for survey dates). Overall, these point measurements are within the range of water temperatures thought to be suitable for rearing ammocoetes; although maximum daily water temperatures were likely considerably higher at some sites both on the survey dates and other dates.

Stream flows were not measured for survey reaches, but lack of rainfall in the region during Water Year 2014 resulted in flows that were well below average within the Eel River basin study area—during both winter and summer survey periods (Table 2-6). For example, in Bull Creek mean discharge in December 2013 and January 2014 was only 1% of the mean discharge in those months during the period of record (1961–2013). Surveys conducted in summer 2014 documented substantial lengths of channel with no to little flow and only small, isolated pools in several streams (e.g., Figure 2-9). Other streams had much lower flows than in a typical winter or summer, with sub-surface flow occurring in many higher-gradient riffles and considerable areas of otherwise suitable ammocoete habitat that was dry.

Table 2-6. Comparison of monthly mean discharge during Water Year 2014[1] with the period of record for selected gages near the project study area.

Month	Van Duzen River (USGS Gage 11478500)			South Fork Eel River (USGS Gage 11476500)			Bull Creek (USGS Gage 11476600)		
	Mean discharge (cfs)		% of normal	Mean discharge (cfs)		% of normal	Mean discharge (cfs)		% of normal
	1951–2013	WY 2014		1940–2013	WY 2014		1961–2013	WY 2014	
October	127	45	35%	234	63	27%	11	3.0	27%
November	774	37	5%	1,280	74	6%	89	3.4	4%
December	1,890	27	1%	4,040	59	1%	262	2.7	1%
January	2,130	35	2%	5,050	53	1%	306	2.3	1%
February	1,940	834	43%	4,580	1,297	28%	286	20	7%
March	1,630	1,972	121%	3,550	3,939	111%	236	133	56%
April	962	566	59%	1,860	1,487	80%	122	90	74%
May	457	98	21%	720	224	31%	42	14	34%
June	148	26	18%	308	84	27%	18	4.8	27%
July	37	8.0	22%	112	38	34%	6.8	1.1	16%
August	16	3.1	19%	58	14	25%	3.2	0.2	6%
September	18	5.9	33%	56	18	33%	2.5	0.7	28%

[1] 1 October 2013–30 September 2014

Figure 2-9. Examples of dry or intermittent stream reaches encountered during summer 2014 ammocoete distribution surveys. Upper left, Blanton Cr. Upper right, Cuneo Cr. Lower left, Root Cr. Lower right, Grizzly Cr.

2.1.2.2 Index site relative abundance surveys

Densities

Table 2-7 summarizes densities of ammocoetes (≥ 50 mm) captured in sample quadrats at each index site surveyed in 2014.

Table 2-7. Minimum, maximum, and mean numbers of ammocoetes (≥ 50 mm) captured by species in 1-m^2 samples at index sites surveyed in 2014.[1]

River	Index site	N	ET density		LS density		UK density		All ammocoetes	
			Range	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)
Eel	EI1	30	0–9	3.0 (0.4)	0–18	7.7 (0.8)	0–4	0.8 (0.2)	0–26	11.5 (1.1)
	EI2	30	0–11	3.4 (0.5)	0–22	9.1 (0.9)	0–9	2.7 (0.5)	1–35	15.2 (1.3)
Van Duzen	VDI1	30	0–4	1.1 (0.2)	0–2	0.4 (0.1)	0–2	0.3 (0.1)	0–5	1.7 (0.3)
	VDI2	30	0–5	1.5 (0.2)	0–4	1.0 (0.2)	0–2	0.2 (0.1)	0–6	2.7 (0.3)
All sites		120	0–11	2.3 (0.2)	0–22	4.6 (0.5)	0–9	1.0 (0.2)	0–35	7.8 (0.7)

[1] ET = *Entosphenus* or Pacific lamprey, LS = *Lampetra* species, UK = unknown species

Mean density of Pacific lamprey ammocoetes was significantly higher at the Eel River index sites compared with the Van Duzen River sites (two-sample *t*-test; df = 118, $P < 0.0001$). However, mean density of Pacific lamprey ammocoetes was not significantly different between the two Eel River index sites (two-sample *t*-test; df = 58, $P = 0.5465$) or between the two Van Duzen River index sites (two-sample *t*-test; df = 58, $P = 0.1960$) (Figure 2-10).

In the Eel River, *Lampetra* ammocoete density was significantly higher than Pacific lamprey density at both sites (Figure 2-10). However, in the Van Duzen River, Pacific lamprey density was higher than *Lampetra* density at both index sites; although this difference was only significant at VD1 (paired two-sample *t-test*; df = 29, P = 0.0054). Finally, only four eyed Pacific lampreys (all classified as partially transformed ammocoetes) were captured at index sites: three at EI1 and one at VDI2.

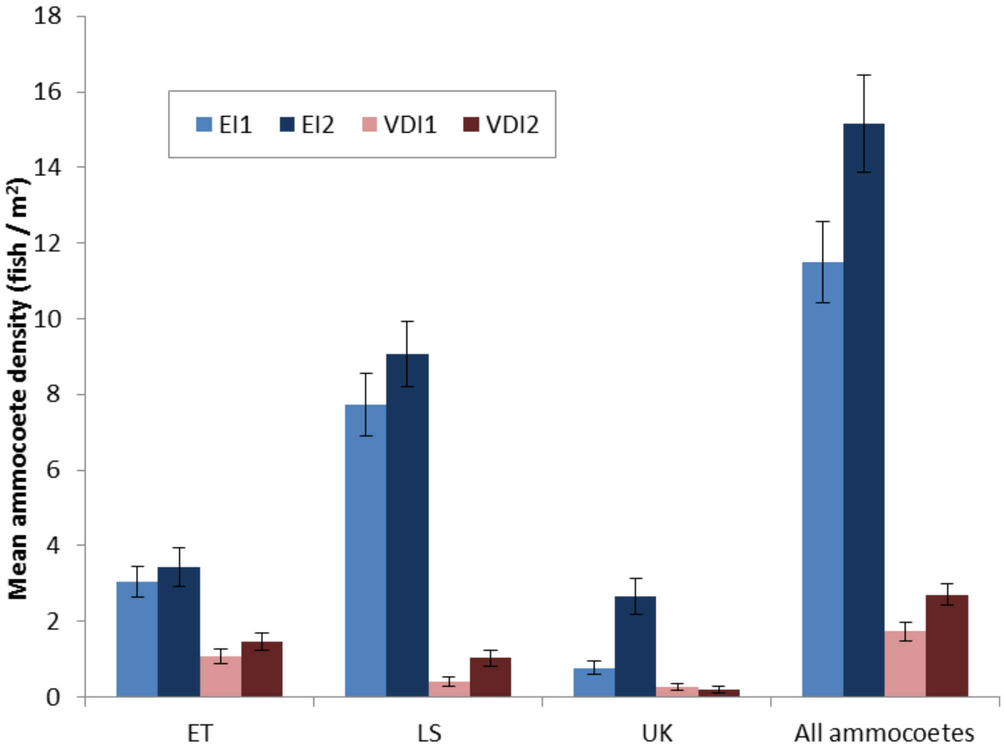


Figure 2-10. Mean density of ammocoetes ≥50 mm by species at each index site. Bars represent standard errors. ET = *Entosphenus* or Pacific lamprey, LS = *Lampetra* species, UK = unknown species.

In both the Eel and Van Duzen rivers, mean length of Pacific lamprey ammocoetes was greater at the downstream site (EI1 and VDI1) compared with the upstream site (EI2 and VDI2) (Table 2-8, Figure 2-1). This difference was highly significant for Eel River sites (two-sample *t*-test; df = 192, $P < 0.0001$), but not statistically significant for Van Duzen sites (two-sample *t*-test; df = 74, $P = 0.0757$). At both of the downstream sites, length distributions were skewed towards the larger size classes relative to the upstream sites in the same river (Figure 2-11).

Table 2-8. Minimum, maximum, and mean lengths of Pacific lamprey ammocoetes (≥50 mm) captured at index sites surveyed in 2014.

Site	N	Pacific lamprey ammocoete length (mm)	
		Range	Mean (SE)
EI1	91	61–139	87.4 (1.6)
EI2	103	50–120	77.4 (1.4)
VDI1	32	56–134	86.2 (3.3)
VDI2	44	50–112	79.9 (1.8)
Total	**270**	**50–139**	**82.2 (0.9)**

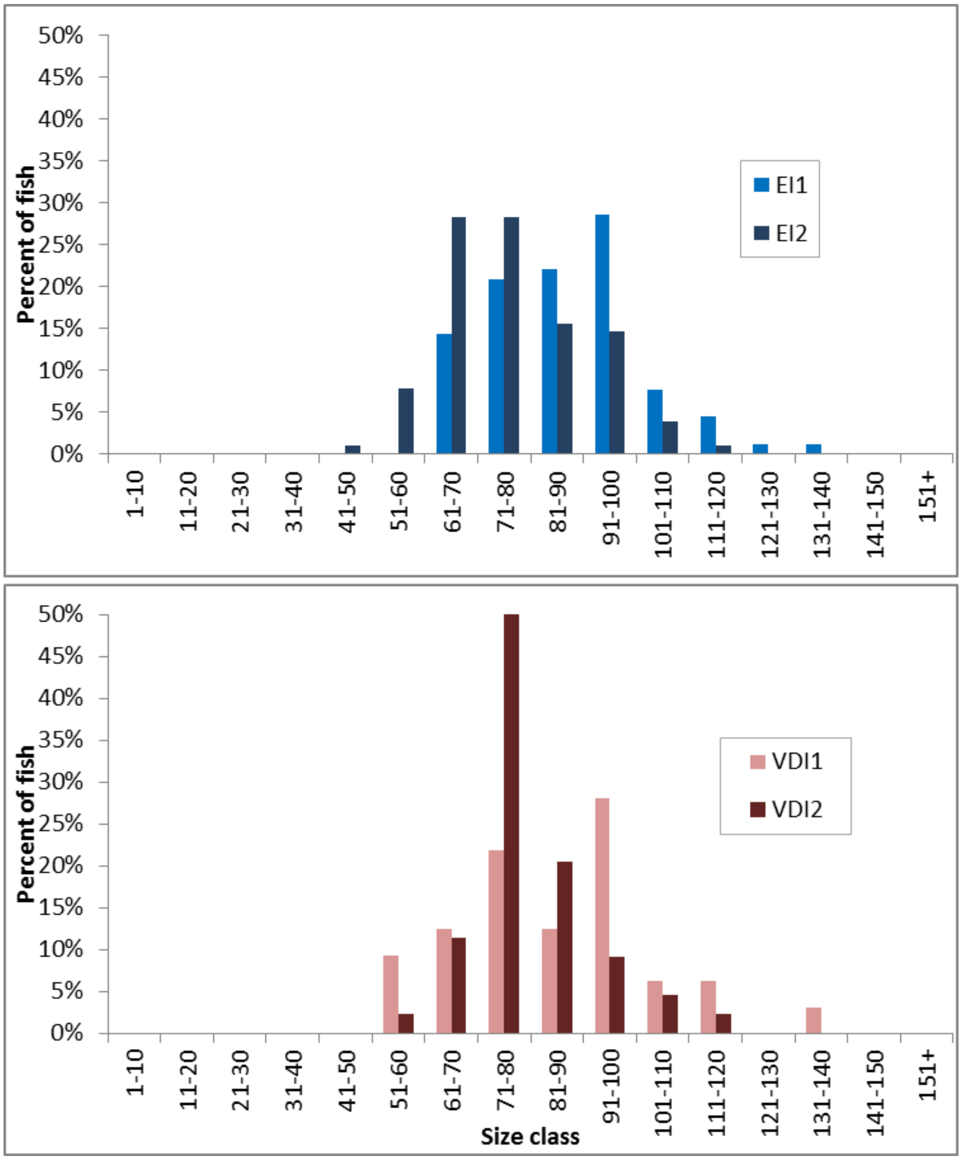


Figure 2-11. Percentage of Pacific lamprey ammocoetes captured by length class at each index site in the Eel River (top) and Van Duzen River (bottom).

Sample effort required

Tables 2-9 and 2-10 show results of power analyses to estimate the number of 1-m^2 samples required to statistically detect varying magnitudes of difference in mean density of Pacific lamprey ammocoetes over time (based on variances in densities observed during pilot surveys). For example, at Eel River sites, sampling 15 quadrats at an index site would allow statistical detection of a difference in mean density of 2 fish/m^2 between years using a *paired t-test* (which assumes sample quadrats would be in the same locations each year). For reference, observed densities at Eel River index sites ranged from 3.0 to 3.4 fish/m^2 in 2014. In the Van Duzen River, where observed densities ranged from 1.1 to 1.5 fish/m^2, sampling 15 quadrats at a site would allow detection of a difference in mean density of approximately 1 fish/m^2 between years at a given index site. In addition, as seen in Tables 2-9 and 2-10, a greater number of samples are needed to detect the same difference in density when using *two-sample t-test* compared with using a *paired t-test.*

Table 2-9. Results of power analyses estimating number of 1-m^2 samples needed to detect specified differences in density of Pacific lamprey ammocoetes (≥50 mm) at mainstem Eel River index sites using different t-tests (95% confidence and 80% power).

Difference in mean density (fish/m^2) detectable	Required sample size	
	paired t-test	*two-sample t-test*
5	5	6
4	6	8
3	8	13
2	15	27
1	54	104

Table 2-10. Results of power analyses estimating number of 1-m^2 samples needed to detect specified differences in density of Pacific lamprey ammocoetes (≥50 mm) at Van Duzen River index sites using different t-tests (95% confidence and 80% power).

Difference in mean density (fish/m^2) detectable	Required sample size	
	paired t-test	*two-sample t-test*
3	4	4
2	5	7
1	14	24
0.5	46	90
0.25	179	354

Habitat relationships

Various analyses revealed few meaningful relationships between the number of ammocoetes (≥50 mm; all species) captured in 1-m^2 sample quadrats (i.e., density) and the habitat variables measured (Appendix B). The only relatively strong relationship with ammocoete density was at the two Eel River index sites, where there was a significant positive linear relationship between ammocoete density and distance from the nearest bank (r^2= 0.4519; P < 0.0001) (Figure 2-12). However, this relationship was not significant at the Van Duzen River sites (r^2= 0.0335; P = 0.1615).

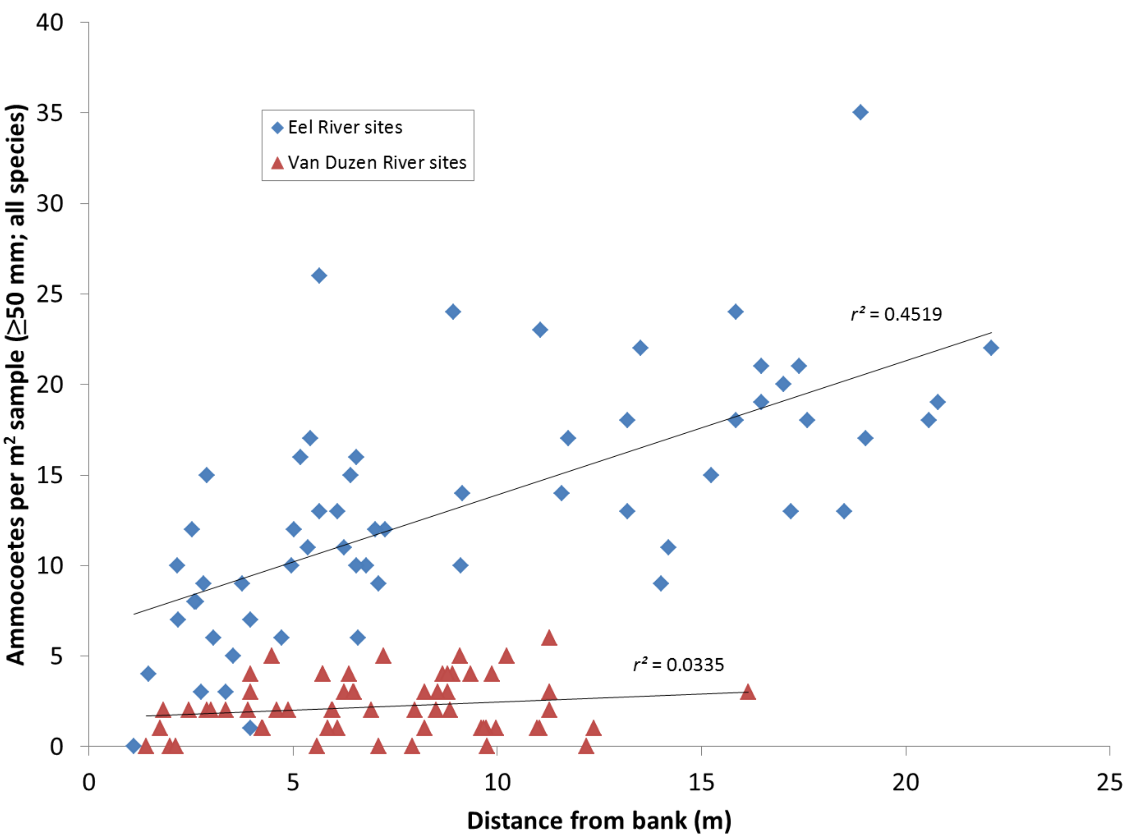


Figure 2-12. Number of ammocoetes (all species) captured in sample quadrats versus distance from the nearest bank at Eel and Van Duzen river index sites.

Results of the full ANOVA model, considering all covariates together, indicated that ammocoete density at the Eel River sites was not strongly related to any of the habitat variables measured, other than distance from bank (Appendix B, Tables B-3 and B-4). ANOVA results for the Van Duzen River suggested ammocoete density was weakly related to distance upstream (distance of the sample quadrat from the downstream end of the site). Linear regressions of one covariate at a time (in addition to site) for each river generally confirm results of the full ANOVA model (Appendix B).

The unexpected relationship, in the Eel River data, between ammocoete density and distance from the bank, combined with the absence of a relationship between density and other covariates, such as water depth, which might seem more biologically logical, led us to explore the distance from bank relationship in more detail. Appendix B (Tables B-1 and B-2) shows correlations among the different covariates for Eel River and Van Duzen River index sites. In addition to being correlated with ammocoete density, distance from the bank in the Eel River was correlated to some extent with all covariates except water depth. However, since none of these covariates had any value as a predictor of density (Appendix B, Tables A-3 and A-5), distance from the bank does not appear to be acting as a surrogate for some other measured variable. We also used non-parametric regression to evaluate nonlinearity in the linear regression model between ammocoete density and distance from the bank (Appendix B, Figure B-1). This analysis confirms that a relatively strong relationship between these variables was present at both Eel River sites and that the relationship was *not* significantly non-linear (i.e., was consistent with linearity).

2.1.3 Discussion

2.1.3.1 Distribution surveys

We detected Pacific lamprey ammocoetes in five streams where the species had not been previously documented (Stillwater Sciences 2014a): Price, Shaw, South Fork Yager, and Grizzly creeks and Booths Run. We also located the species in Lawrence Creek as far upstream as Bell Creek, but did not sample farther upstream where several miles of relatively low-gradient channel exists. No Pacific lampreys were detected in the other eight streams sampled during distribution surveys. While we put considerable effort into detecting species presence in these streams, lack of capture does not definitively signify complete absence. Nonetheless, our results provide strong evidence that Pacific lamprey ammocoetes were likely absent or extremely rare in those streams during 2013–2014 surveys, especially in those streams where numerous patches of suitable habitat were sampled. Various studies have demonstrated that the AbP-2 e-fisher has relatively high capture efficiency for ammocoetes at the settings used in this study (Steeves et al. 2003, Luzier et al. 2006). This high capture efficiency translates into a high probability of detection when moderate numbers of ammocoetes are present in a survey reach (Starcevich and Clements 2013, Dunham et al. 2013, Reid and Goodman 2015). For the streams in which we did detect Pacific lampreys, they were always found in the first 100-m sample segment that contained a suitable wetted habitat patch larger than approximately 2 m^2. Reid and Goodman (2015) found that detection probability of Pacific lamprey at a single site in watersheds where they were present was >90% when targeting suitable habitat relatively low in the watershed. They also found that sampling a total of three sites provides >95% confidence that Pacific lampreys are not present upstream.

Thus, for streams in our survey reaches where we sampled moderate to high quantities of suitable ammocoete habitat (Table 2-3), we can also reasonably presume that, upstream of the survey reach, the species was extremely rare or not present. Ammocoetes generally move downstream from spawning areas, and therefore we expect them to be present in suitable habitat in the most downstream reaches of a stream if they are present in upstream reaches. For all but two streams in which Pacific lampreys were not detected, at least 1,000 m of channel (starting at the confluence with larger streams) was surveyed <u>or</u> at least 10 highly suitable (Type I) ammocoete habitat patches with an area greater than 1 m^2 were sampled over a minimum of 300 m of channel. In Blanton Creek, 700 m of channel (and 7 suitable habitat patches >1 m^2) were surveyed before the channel gradient increased sharply and the stream became mostly dry. In Cuneo Creek, the survey was halted after the channel became mostly dry and there were safety concerns about private property.

The absence of Pacific lamprey ammocoetes in Strongs Creek—a relatively large (44 km^2 drainage area) and low-gradient stream that had ample water, large areas of apparently suitable fine-sediment habitat, and moderate numbers of *Lampetra* ammocoetes—warrants further investigation. Absence of ammocoetes in Bear Creek also merits additional research, since this relatively large stream (22 km^2 drainage area) had ample water and substantial quantity of apparently high-quality, fine-sediment habitat.

Despite the strong evidence for absence in the streams where Pacific lampreys were not detected, we cannot rule out their presence or the use of these streams for holding, spawning, or rearing in years with better habitat conditions. The severe drought in water year 2014 and associated low water levels may have also led to absence in certain streams where ammocoetes would be found during a more normal water year. 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 dry reaches. For instance, we were unable to sample Root Creek in summer 2014 due to lack of wetted habitat, but numerous *Lampetra* ammocoetes were captured there in the vicinity of the survey reach during summer 2013 (Stillwater Sciences 2014b). The seemingly very high densities of ammocoetes documented by index site surveys in the mainstem Eel and Van Duzen rivers supports the hypothesis that many ammocoetes were forced to leave drying tributaries. For those streams that went completely dry, the impact of the drought on ammocoete distribution and age distribution may last for several years until recolonization occurs. It is also possible that loss of ammocoetes will result in decreased spawning or even local extirpation in these streams due to lack of the pheromone-like compounds secreted by ammocoetes that are thought to attract adults to spawning areas (Robinson et al. 2009, Yun 2011).

Because of the extreme drought during 2014 surveys, conducting additional distribution surveys during wetter conditions in streams where no Pacific lamprey were detected would be valuable. Likewise, many small- to moderate-sized streams in the study area that are typically perennial could not be sampled during this study due to lack of water. Other streams had isolated pools containing water, but unless the pools were large, they were not sampled to avoid the possibility of stressing trapped salmonids. These streams will be sampled during planned future distribution surveys (Section 3).

Although the 2014 distribution survey methods were not designed to estimate ammocoete abundance, results from distribution surveys provide coarse estimates of relative abundance (fish/100 m) of Pacific lamprey and *Lampetra* ammocoetes in survey reaches. If surveys are conducted in the same reaches in future years using the same methods and level of effort, observed relative abundances may be used for detecting relatively large changes in the ammocoete population within each reach. Relative abundance of ammocoetes within each rather short survey reach, however, is not necessarily representative of relative abundance in the stream as a whole. For example, in some survey reaches, entire 100-m segments did not contain suitable habitat and therefore were not electrofished—but these channel lengths of these segments were included in calculations of fish/100 m for the larger reaches surveyed. It is expected that relative abundance varies within reaches of a given stream due to inherent variability in habitat quantity and quality and patchy distribution of ammocoetes. Additionally, caution should be used when comparing relative abundance between survey reaches in different streams. While overall electrofishing effort per area of suitable habitat was relatively constant between streams (excluding Grizzly Creek and Booths Run), potential differences in factors affecting capture efficiency between streams (e.g., sediment depths, water conductivity, water depth and visibility) could impact conclusions about relative abundance.

Distribution surveys were also designed to help quantify availability of suitable ammocoete habitat and describe important habitat characteristics such as quantity of LWD in each reach. Since we only measured wetted habitat area, interpretation of suitable habitat data should be done in the context of stream flows. The extreme drought during summer 2014 surveys likely resulted in marked reduction in suitable habitat availability compared with years and seasons with higher stream flows, where greater areas of fine substrates along stream margins are wetted.

2.1.3.2 Index site surveys

Densities

The relatively high densities of ammocoetes captured at index sites in the lower mainstems of Eel and Van Duzen rivers, combined with the very large patches of high quality habitat found there, indicate that these locations are likely extremely important for the overall lamprey population in lower portions of the Eel River watershed (and probably the entire watershed). The relative importance of these large rivers for ammocoete rearing compared with smaller tributaries may be even higher in drought years such as 2014 when many of the tributaries had little or no flow. Because of the drought during early fall 2014 index sites surveys, stream flows (and presumably area of suitable ammocoete habitat that was wetted) were much lower than a typical year (e.g., Table 2-5). For this reason, effective ammocoete densities in the condensed suitable habitat may have been higher than in a typical year, even if the overall numbers of fish at these sites were the same.

Importantly, the ammocoete densities reported for index sites are not "true" densities, since a single 90 s electrofishing pass is not expected to capture all the ammocoetes present in each quadrat. For this reason, caution should be used when comparing values from this study with those reported in other studies, particularly if methods and sampling effort varied. However, we can assume that the densities derived from these methods are an acceptable measure of relative abundance that can be compared between quadrates, sites, and time when consistent sampling methods and effort are applied.

Only small numbers of transforming (eyed) Pacific lamprey ammocoetes were captured during index sites surveys, and none were captured during distribution surveys. Since our surveys were designed primarily to target preferred ammocoete habitats, they are likely not a reliable indicator of relative abundance of transforming ammocoetes, which are thought to have different habitat preferences. During metamorphosis, Pacific lampreys typically (but not always) move from fine substrates in low-velocity areas to coarser substrates with moderate current and higher dissolved oxygen content (Richards and Beamish 1981). Including these habitats in electrofishing surveys would be needed to effectively monitor macrophthalmia.

Sample effort needed

Based on observed variances in ammocoete densities, fifteen samples are required to statistically detect differences of 2 fish/m^2 and 1 fish per m^2 at Eel and Van Duzen river index sites using a *paired t-test*, respectively. Despite the small magnitude of these differences, they make up a relatively large percentage of the densities observed in each river during the 2014 pilot surveys (approximately 66%). Consequently, more than 15 samples would need to be collected in order to detect inter-annual differences smaller than 66% of observed densities. These considerations will be discussed further and taken into account when recommending sample size guidelines for index sites for long-term monitoring (Section 3).

Habitat relationships

Results of statistical analyses evaluating the relationships between ammocoete density and habitat variables in the Eel River demonstrate that it is important to account for the distance-from-bank when designing a sampling approach for index sites in these large streams. This can be accomplished by spreading samples out uniformly across the channel within the boundaries of each index site, as was done in the pilot surveys. The mechanisms leading to the positive relationship between ammocoete density and distance-from-bank at Eel River sites are unknown. One possible explanation is that there is higher predation on ammocoetes rearing in the generally shallower waters closer to the bank by land-based predators. Alternatively, sites farther from the bank may provide greater protection from dewatering and desiccation. The weak but significant relationship between ammocoete density and distance from the downstream end of the site (*dist.us*) found at Van Duzen River sites suggests sample quadrats should continue to be spread out from the downstream to upstream ends of each site. Additional discussion of these results in the context of long-term monitoring is presented in Section 3.

2.2 Spawning Surveys

Pilot Pacific lamprey spawning surveys were conducted in 2014 to document presence and seasonal patterns of spawning in the study area and to test and refine field protocols for long-term monitoring. Methods and results from these surveys are described below.

2.2.1 Methods

Between 18 March and 25 June 2014, Pacific lamprey spawning surveys were conducted at least once in 15 reaches encompassing 62 km of channel in seven streams (Table 2-11, Figure 2-13). Surveys were categorized as either “bi-weekly” or “peak”. Bi-weekly surveys were conducted in select reaches of Bull and Lawrence creeks from late March through late June to describe seasonal patterns in spawning activity and annual abundance of redds in these more intensively studied streams. Lawrence and Bull creeks were selected for more intensive surveys due to their moderate size, wadeability, and ease of access. A short reach of lower Booths Run was surveyed opportunistically on three occasions in attempts to document spawning while surveying an adjacent Lawrence Creek reach.

Peak surveys were conducted immediately after the anticipated peak spawning period (late May to mid-June) in select reaches of larger, generally unwadeable streams. The purposes of these surveys were to help understand distribution and relative abundance of spawning in these reaches, test and refine methods for surveying larger streams, and help identify suitable index reaches for long-term monitoring.

Table 2-11. Stream reaches in the Eel River basin study area where Pacific lamprey spawning surveys were conducted in 2014.

Stream	Reach ID	Downstream end	Upstream end	Reach length (km)	Drainage area (km^2)[1]	Survey type	Survey date or period	# of surveys
Eel River	E1	Fernbridge	River Lodge	6.7	9,303	Peak	6/18	1
	E2	Holmes	SF Eel confluence	7.7	7,841	Peak	6/6	1
Van Duzen River	VD1	Hwy 101 Bridge	Fischer Road	6.9	1,106	Peak	5/29	1
	VD2	Grizzly Cr CG	Golden Gate Bridge	7.4	574	Peak	5/28	1
Yager Cr	Y1	Lower Yager Cr	Cooper Mill Cr	2.0	343	Peak	5/19	1
	Y2	Blanton Cr	Lawrence Cr	2.2	307	Peak	5/19	1
	Y3	Lawrence Cr	Strawberry Cr	1.9	195	Peak	5/19	1
	Y4	Strawberry Cr.	Unnamed stream	2.3	187	Peak	5/19	1
Lawrence Cr	LC1	HRC Road 3	HRC Road 8	2.3	105	Bi-weekly	3/25–6/19	7
	LC2	Skid road	Spur road bridge	1.3	61	Bi-weekly	4/10–6/19	6
Booths Run[2]	BR1	Lawrence Cr confluence	~400 m upstream	0.4	15	Opp[2]	4/22–5/21	3
South Fork Eel River	SF1	Redway	Tooby Park	8.7	1,303	Peak	6/4	1
	SF2	Tooby Park	Benbow	8.4	1,203	Peak	6/2	1
Bull Cr	BC1	Tepee Cr	Cow Cr	1.6	103	Bi-weekly	3/18–6/25	8
	BC2	Mill Cr	Cuneo Cr	2.2	55	Bi-weekly	3/18–6/25	8

[1] Approximate contributing drainage area at the downstream end of each survey reach.
[2] Opportunistic surveys conducted three times during surveys of LC2.

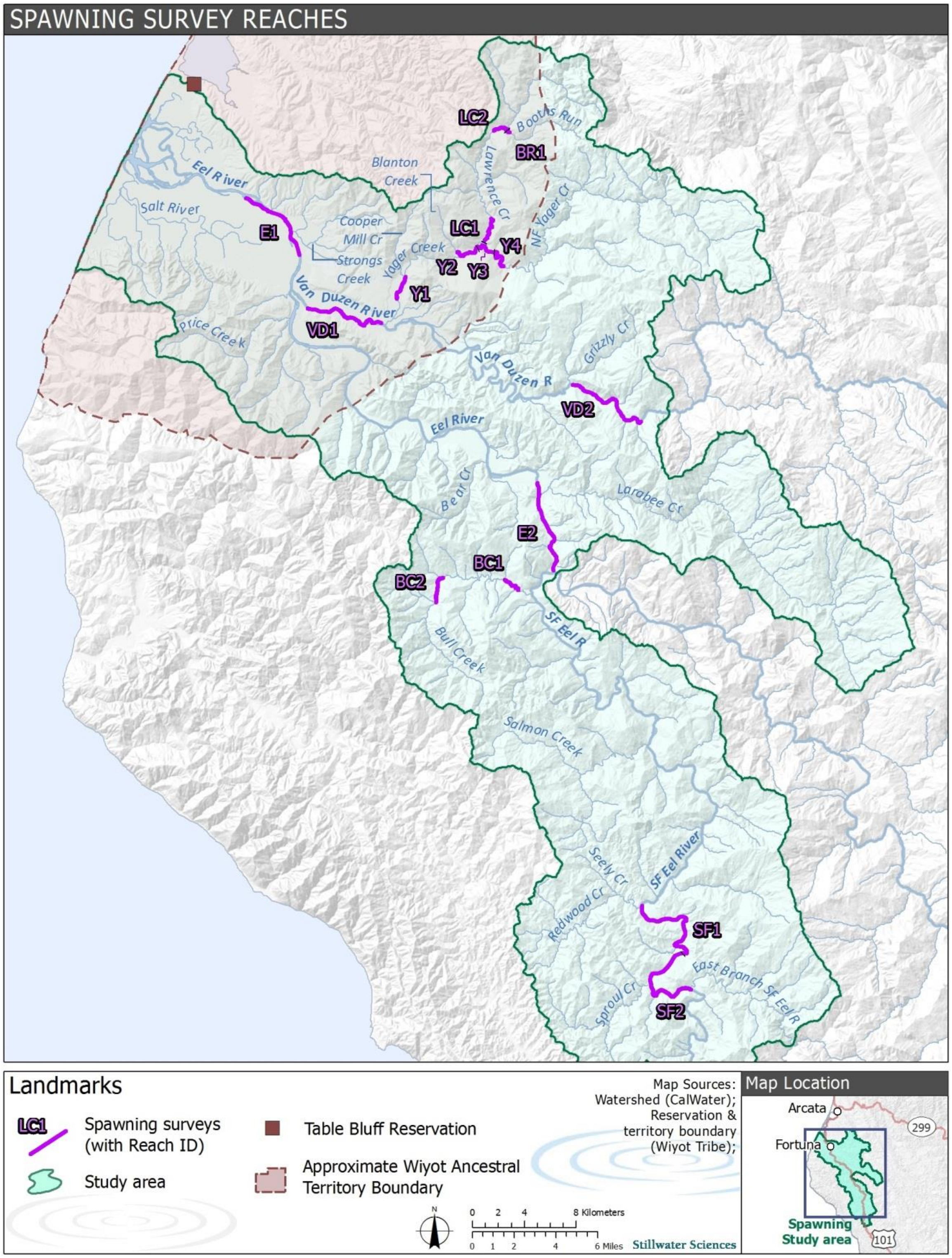


Figure 2-13. Locations of reaches where spawning surveys were conducted in 2014.

2.2.1.1 Bi-weekly surveys

Bi-weekly spawning surveys were designed to count every Pacific lamprey redd constructed during the spawning season. The bi-weekly sampling periodicity was selected to ensure all new redds could be easily detected based on the amount of time lamprey redds typically remain visible in regional streams (C. Anderson, CDFW, pers. comm., A. Brumo pers. obs, Stone 2006). Bi-weekly surveys were timed to begin prior to the onset of spawning and end after not detecting new redds for two consecutive surveys of a given stream.

Field protocols for bi-weekly surveys were based in large part on methods used by the CDFW Anadromous Fisheries Resource Assessment and Monitoring Program to monitor anadromous salmonids and Pacific lampreys in Northern California coastal streams (protocols provided by C. Anderson, CDFW). During each survey, all visible Pacific lamprey redds, adults, and carcasses were counted. Two or three observers surveyed the entire channel visually by wading or walking the stream margin in the downstream to upstream direction. All areas of disturbed substrate encountered were carefully examined to determine whether they were created by Pacific lamprey based on the shape and area of disturbance and substrate size and sorting patterns. Subjectivity exists in redd characterization, but we generally defined lamprey redds as roughly circular depressions (~0.5 x 0.5 m) in the streambed, where most substrate larger than pea-gravel (~6–10 mm) is piled on one or more sides of the depression and not well-sorted by size. Inexperienced observers can misidentify steelhead redds as lamprey redds and vice versa. However, unlike lamprey redds, steelhead redds typically have larger substrate remaining in the redd depression and a more defined tail-spill that is found only on the downstream side of the depression and sorted by substrate size (with smaller particles further downstream). During surveys, only redds deemed to be complete were counted. We assumed that partially completed redds would be counted during a later survey if they appeared to be complete by that time.

Locations of each redd counted were recorded using a handheld GPS unit and marked with colored flagging tied to the nearest downstream tree branch. The distance and compass bearing from the flagging to the redd were recorded to allow the exact location to be determined on subsequent surveys to avoid recounting and to help evaluate detectability of individual redds over time. When re-encountering flagging denoting presence of a redd counted on subsequent surveys, the condition of the redd was noted to help assess the duration redds remained detectible. Redd condition and level of detectability was qualitatively categorized as one of the following:

- *new since last survey,*
- *still distinct (easy to detect, with minimal large gravel or cobble substrate in redd pot),*
- *detectible but difficult to see (not obvious, typically due to substrate on edges of redd crumbling into pot and/or growth of periphyton),*
- *or no longer detectible.*

Ability of surveyors to detect redds over time was assessed by systematically reviewing redd condition data and associated survey dates and determining level of detectability for each redd after 15, 30, and 45 days since the initial detection date.

When live adult lampreys were observed during surveys, the following information was collected when possible: species, sex, GPS coordinates, and whether the fish appeared to be associated with a redd. When lamprey carcasses were observed, species, sex, length, interdorsal length, and GPS coordinates were recorded.

Other information collected during surveys included water clarity (feet of visibility), water temperature, qualitative characterization of spawning habitat quality, and presence of adult steelhead and their redds. A continuous temperature logger was launched in the lower Bull Creek survey reach to help understand the relationship between water temperature and spawning activity.

2.2.1.2 Peak surveys

Peak spawning surveys were conducted soon after the anticipated peak spawning period (late May to mid-June) in two reaches in the lower mainstem Eel, Van Duzen, and South Fork Eel rivers and four reaches of Yager Creek (Table 2-11, Figure 2-13). As with bi-weekly surveys, the focus of these surveys was enumerating redds, but live fish and carcasses were also counted.

For unwadeable streams (Eel, Van Duzen, and South Fork Eel rivers), detection of redds and spawning lampreys was maximized by snorkeling downstream in tandem with a support boat to help guide snorkelers. The role of the support boat was to record data, carry equipment, assure safety of snorkelers, and make sure they were covering all suitable spawning habitat and investigating all areas where substrate was disturbed. Depending on channel width, three to four observers were spread-out evenly in parallel lanes across the channel followed closely by the data recorder in an inflatable pontoon boat equipped with a small trolling motor. After counting all redds in each habitat unit (i.e., pool, riffle, run), divers would pause and relay data to the data recorder. When necessary, snorkelers would stand up and look for redds in shallow water areas (e.g., shallow pool tailouts) where they could be missed by snorkeling. Communication amongst snorkelers and with the data recorder was critical to avoid double-counting or missing redds or fish. Surveys focused on areas with potentially suitable spawning habitat (gravel and cobble substrates in runs, low gradient riffles, and pool and run tail outs). Long, low velocity runs and pool bodies were typically skipped by towing divers behind the inflatable pontoon boat. Although divers did periodically investigate non-typical spawning habitats to ensure they were not missing redds. If one or more redd, fish, or carcasses were observed, GPS coordinates of the associated habitat unit were recorded. For Yager Creek, which is a wadeable stream, peak surveys were conducted by wading in the upstream direction.

2.2.2 Results

2.2.2.1 Bi-weekly surveys

In Lawrence Creek, seven bi-weekly surveys were conducted in the lower reach (LC1) and six were conducted in the upper reach (LC2) between 25 March and 19 June 2014. A total of 26 redds were counted during the spawning season, 16 in LC1 and 10 in LC2 (Table 2-12). Linear density of redds was 7.1 redds/km in LC1 and 7.1 redds/km in LC2. The first redds of the season in Lawrence Creek were detected on 10 April in LC1, while redds were not detected until 22 April in LC2 (Figure 2-14). The last redd detected in Lawrence Creek was on 5 June in LC1. Overall, spawning activity appeared to start earlier and last longer in LC1 compared with LC2 (Figure 2-14). No spawning adult Pacific lampreys were observed in Lawrence Creek, but a single carcass of unknown sex measuring 390 mm was found in LC1 on 5 June 2014.

Eight bi-weekly surveys were conducted in each of the two Bull Creek survey reaches between 18 March and 24 June 2014. During this period, three Pacific lamprey redds were counted in the lower reach (BC1) and eight redds were counted in the upper reach (BC2) (Table 2-12). The first redd was detected on 15 April in BC1 and the last redds were detected on 10 June in BC2 (Figure 2-15). No redds were detected in either reach during the first two surveys (18 March and 8 April).

Based on the small number of redds counted in 2014, spawning activity started, peaked, and ended earlier in the upper reach (BC2) compared with the lower reach (BC1). No spawning Pacific lamprey adults or carcasses were observed during Bull Creek surveys. Based on detection of newly-constructed redds, the length of the spawning season was relatively similar between Bull and Lawrence Creeks, but the peak redd count was approximately three weeks earlier in Lawrence Creek (Figures 2-14 and 2-15). Linear densities of redds in Bull Creek were considerably lower than Lawrence Creek: 1.9 and 3.6 redds/km in BC1 and BC2, respectively (Table 2-12).

A single Pacific lamprey redd was detected in Booths Run, a small tributary to Lawrence Creek, on 22 April 2014 during an opportunistic survey of the lower 0.4 km of the stream. Additionally, a single redd was incidentally observed in the lower 100 m of Shaw Creek (another small tributary to Lawrence Creek) during an ammocoete distribution survey conducted on 22 July 2014 (Figure 2-1). No definitive western brook lamprey, *Lampetra richardsoni*, redds were observed during bi-weekly surveys; though suitably-sized spawning gravel was present in most reaches. It is likely that some western brook lamprey redds were overlooked due to their small size and since surveyors' primary focus was finding Pacific lamprey redds in larger substrates.

Table 2-12. Number of redds, spawning adults, and carcasses counted during bi-weekly surveys in 2014.

Stream	Survey period	Reach ID	Reach length (km)	Redds counted	Linear density (redds/km)	Spawning adults	Carcasses
Lawrence Cr	3/18–6/19	LC1	2.3	16	7.1	0	1
		LC2	1.3	10	7.7	0	0
Booths Run	4/22–5/21	BR1	0.4	1	2.5	0	0
Bull Cr	3/18–6/24	BC1	1.6	3	1.9	0	0
		BC2	2.2	8	3.6	0	0

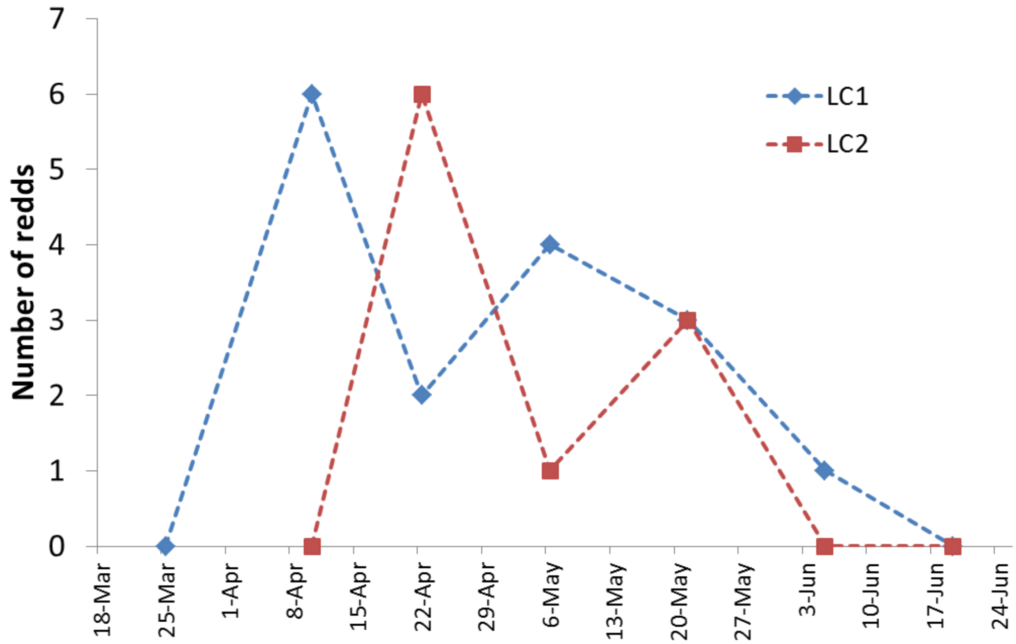


Figure 2-14. Number of Pacific lamprey redds observed in each reach of Lawrence Creek during bi-weekly surveys in 2014.

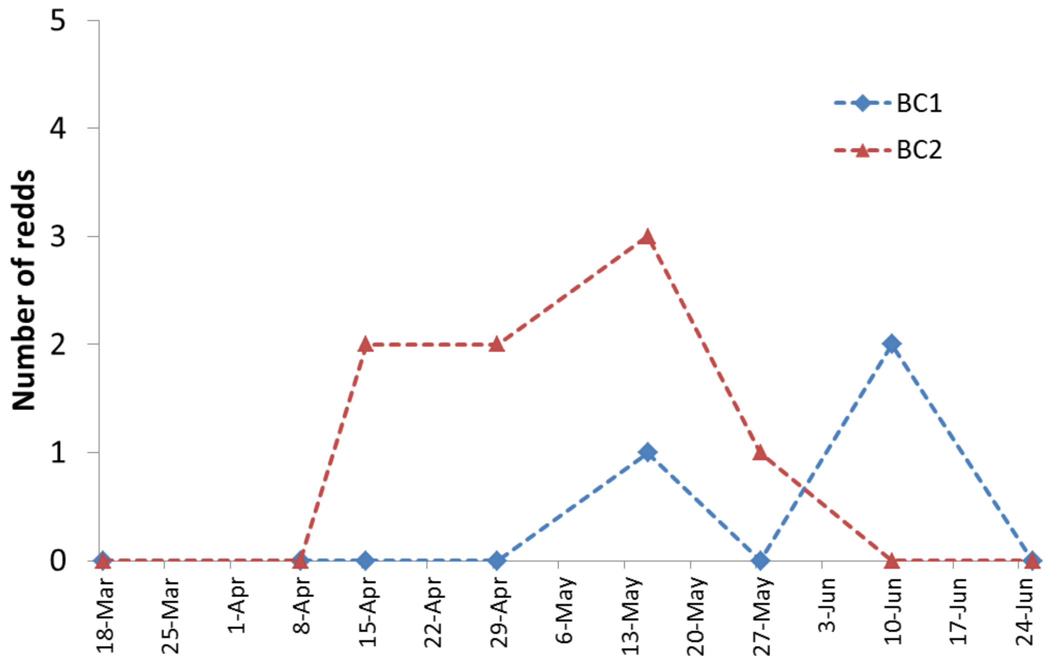


Figure 2-15. Number of Pacific lamprey redds observed in each reach of Bull Creek during bi-weekly surveys in 2014.

The ability of surveyors to detect previously counted redds on Lawrence and Bull creeks decreased with days since first detection (Figure 2-16). After 15 days, 65% of redds were still distinct (clearly visible) and 86% were still detectible (including those categorized as *distinct* and *detectible but difficult to see*). However, after 30 days only 24% of redds were still distinct, while 62% were still detectible. After 45 days, only 29% were still detectible (Figure 2-16).

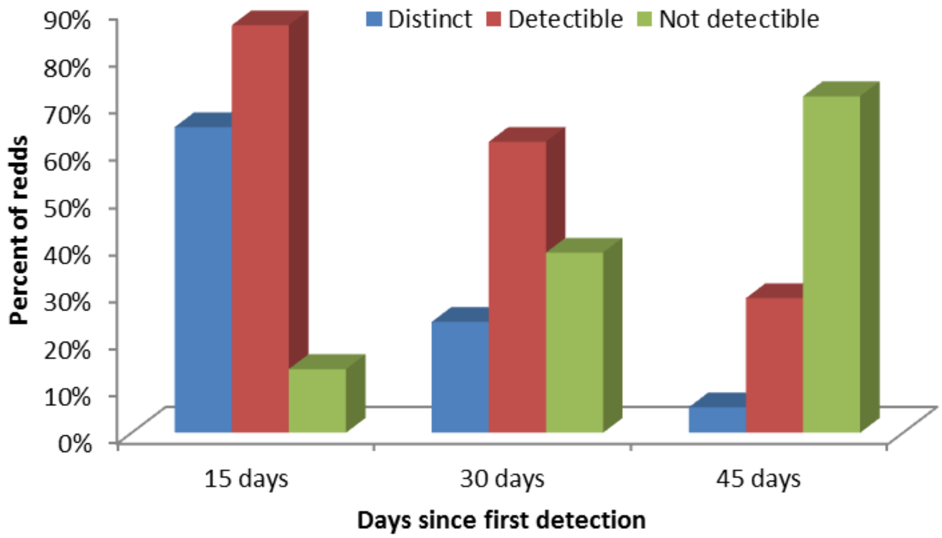


Figure 2-16. Percentage of Pacific lamprey redds still distinct, detectible (including those categorized as distinct), and not detectible versus time since first detection.

Instantaneous water temperatures in Bull Creek ranged from approximately 11°C to 20°C during the period in which new redds were detected (Figure 2-17). Water temperatures measured with a handheld thermometer in Lawrence Creek ranged from 9°C to 14°C during the period when redds were detected. With the exception of two back-to-back, moderate peaks in stream discharge in late March and early April, discharge dropped steadily throughout the survey period in both streams, reflecting the exceptionally dry winter and spring (Figure 2-17).

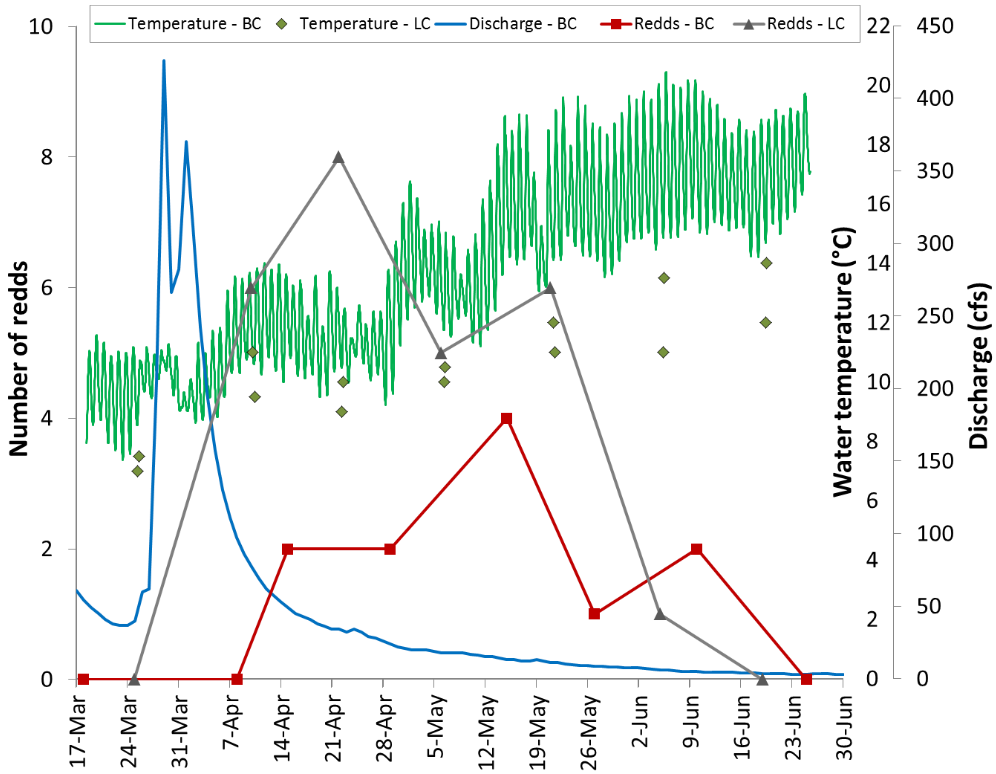


Figure 2-17. Number of Pacific lamprey redds counted in Bull (BC) and Lawrence (LC) creeks, water temperatures, and daily mean discharge during the survey period. Discharge and continuous water temperature data were not available for Lawrence Creek. Bull Creek discharge data from USGS gage #11476600.

2.2.2.2 Peak surveys

Nearly 700 Pacific lamprey redds were counted during peak spawning surveys conducted in the mainstems of the Eel, Van Duzen, and South Fork Eel rivers and Yager Creek (Table 2-13). Only one live spawning adult and three carcasses were observed during these surveys, all in the Van Duzen River. In the Eel River, the upper reach (E2) had substantially higher linear redd densities than the lower reach (E1): nearly 20 times more redds were counted per kilometer of channel surveyed (Figure 2-18). The upper reach on the Van Duzen (VD2) had the highest linear density of redds of any reach surveyed—nearly 25 redds per kilometer, a density five times greater than the lower reach (VD1). Redd densities in Yager Creek survey reaches ranged from 1.5 to 4.4 redds per kilometer (Figure 2-18). In the South Fork Eel River survey reaches, redd densities were approximately 16 and 19 redds per kilometer in SF2 and SF1, respectively.

Table 2-13. Number of redds, spawning adults, and carcasses counted during peak surveys in 2014.

Stream	Reach ID	2014 survey date	Discharge during survey (cfs)[1]	Reach length (km)	Redds counted	Spawning adults	Carcasses
Eel River	E1	18-Jun	183	6.7	6	0	0
	E2	6-Jun	336	7.7	147	0	0
Van Duzen River	VD1	29-May	54	6.9	36	1	2
	VD2	28-May	55	7.4	178	0	1
Yager Creel	Y1	19-May	N/A[2]	2.0	3	0	0
	Y2	19-May	N/A[2]	2.2	9	0	0
	Y3	19-May	N/A[2]	1.9	3	0	0
	Y4	19-May	N/A[2]	2.3	10	0	0
SF Eel River	SF1	4-Jun	110	8.7	162	0	0
	SF2	2-Jun	118	8.4	135	0	0
Total	--	--	--	**54.2**	**689**	**1**	**3**

[1] Based on nearest USGS gage: Eel R. at Scotia, Van Duzen R. near Bridgeville, and South Fork Eel R. near Miranda.
[2] Gage data not available for watershed: Van Duzen River gage should be used as proxy for assessing survey flows.

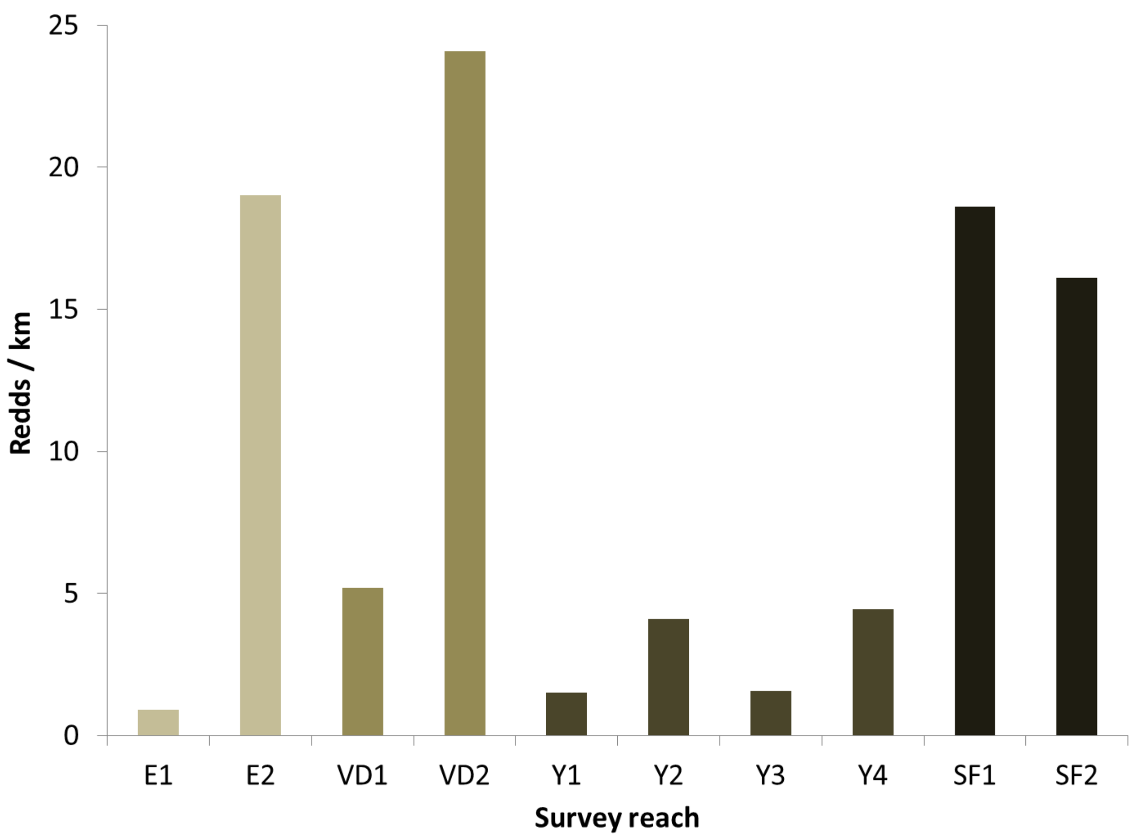


Figure 2-18. Linear density of redds (number per kilometer of channel surveyed) from 2014 peak spawning surveys in the Eel River, Van Duzen River, Yager Creek, and South Fork Eel River survey reaches.

2.2.3 Discussion

We observed Pacific lamprey redds in all reaches surveyed during 2014 pilot surveys and across a wide range of stream sizes—from the lower mainstream of the Eel River to two small tributaries to Lawrence Creek. The presence of redds in the lower mainstem survey reach (E1) is particularly notable since the reach is just upstream of tidal influence. The early April to mid-June spawning period observed during 2014 bi-weekly spawning surveys in Bull and Lawrence creeks is generally consistent with spawning timing observed in other watersheds in the region (Brumo et al. 2009, Gunckel et al. 2009, Stillwater Sciences et al. 2016).

Redd densities from bi-weekly surveys are not directly comparable to one-time peak surveys (which underestimate redd densities relative to bi-weekly surveys), but results of 2014 monitoring do indicate that redd densities in Bull and Lawrence creeks were considerably lower than in most of the mainstem Eel, Van Duzen, and South Fork Eel river study reaches. Redd densities in Bull and Lawrence creeks were similar to those observed in the lower Van Duzen River reach and Yager Creek, however.

It is possible that fewer lampreys spawned in Bull and Lawrence creeks relative to mainstem reaches following the very dry fall and winter of 2013–2014 (Table 2-5) compared with a more "normal" water year. Radio telemetry studies have shown that Pacific lampreys holding in rivers during the winter may undergo a secondary migration to spawning areas in the late winter or early spring, coincident with high flow events. The lack of rain may have discouraged this secondary migration and resulted in more mainstem spawning in 2014. Chinook salmon spawning activity was also more heavily concentrated in the mainstem of South Fork Eel River during the fall and winter of 2013–2014 compared with wetter years (S. Kannry, CDFW, pers. comm.). Moreover, incidental observations of redds from an unrelated fish habitat surveyed conducted in Bull Creek in May 2015—a water year with much higher winter and spring flows—indicated substantially higher redd densities in the study reaches compared with 2014 (A. Brumo pers. obs). The relationship between winter and spring stream flows and relative use of mainstems versus tributaries for Pacific lamprey spawning should be further investigated as more data are collected as part of long-term monitoring (Section 3).

The survey protocols and timing we applied to bi-weekly surveys were successful for meeting our objectives of describing spawning timing and redd abundance in wadeable streams. The relatively low and dropping stream flows during the 2014 bi-weekly survey period allowed regular surveys with excellent visibility, presumably minimizing survey error. Since nearly 90% of previously counted redds could still be detected after 15 days, our bi-weekly survey interval appeared to be appropriate for counting a high percentage of new redds constructed during the spawning season. Since redds may have been as old as approximately 14 days when they were initially detected, our analysis (Figure 2-16) provides a conservative estimate of the level of detectability at various redd ages. Ability to re-detect redds on subsequent surveys decreased over time as expected, with only about 60% of redds still detectible after 30 days.

We also accomplished our primary objectives for peak surveys by documenting mainstem spawning locations, identifying potential long-term index reaches, and testing spawning survey methods for unwadeable streams. Redd counts from these surveys also provided coarse estimates of relative abundance of spawning activity within each survey reach. However, these one-time peak counts likely underestimated total redd abundance in these reaches for the spawning season. Peak surveys conducted earlier in the season likely missed redds constructed by later-spawning fish, and later peak surveys likely missed redds constructed earlier in the season that were obscured by periphyton growth. These and other potential errors associated with survey timing and periodicity were taken into consideration when making recommendations for long-term monitoring in unwadeable streams (Section 3).

The novel approach of using snorkel surveys to count redds in unwadeable streams provided several advantages compared with traditional boat-based and wading surveys. Snorkeling allowed redds to be more easily seen in deeper water and during windy conditions, which obscure visibility from above the water surface. Additionally, snorkeling allowed older redds to be more easily detected based on the three-dimensional structure of the substrate, which is more difficult to see from above (i.e. the relative elevations of the redd tailspill and pot appear more defined when viewing from stream bed elevation than when viewing from above the water). For these reasons, we documented numerous redds that would not have been seen using traditional survey methods. However, because of the proximity of snorkelers to the stream bed, in some cases they had difficulty spotting areas of disturbed substrate that were not nearby. For this reason, it is important to use a sufficient number of snorkelers to adequately cover the stream channel and to have a support boat to help snorkelers maintain even spacing and locate substrate disturbances.

The near absence of live adult Pacific lampreys and carcasses during 2014 surveys is noteworthy and is in contrast to results reported from other river systems. Over all the study reaches, we documented 726 redds, but only observed one live adult and four carcasses. In comparison, during two seasons of spawning surveys on the South Fork Coquille River in Oregon, Brumo et al. (2009) counted approximately one live adult for every five redds observed and one carcass for every eight redds observed. Similarly, on Cedar Creek in Southern Washington, Stone (2006) counted at least one live adult for every four redds counted during spawning surveys. The relative lack of live adults and carcasses in our Eel River study reaches could be due to behavioral differences in spawning time (i.e., more nighttime spawning) or greater predation on spawning and post-spawn adults. Since peak surveys were conducted only once and timed to occur just after the predicted peak spawning period, it is also possible that much of the active spawning had ceased prior to our surveys.

2.3 Creel Surveys

2.3.1 Methods

In winter 2014, the WNRD implemented a pilot creel survey designed by Stillwater Sciences to help monitor the population of adult Pacific lamprey entering the Eel River from the ocean based on capture in the traditional subsistence fishery by Wiyot lamprey fishers, or “eelers.” The creel survey will be a component of long-term population monitoring, and by improving understanding of the biology, life history, and population health of Pacific lamprey, it will allow the Tribe to more effectively manage and protect the fishery. The primary goals of the 2014 pilot creel survey were to (1) test methods for collecting creel data that allow calculation of an annual catch per unit effort (CPUE) index of relative abundance, and (2) collect biological data that will contribute to an overall understanding of Pacific lamprey in the Eel River basin to help inform understanding of life history and limiting factors.

Two different types of creel survey data were collected: on-site surveys conducted at the mouth of the Eel River (the primary eeling location) and periodic phone interviews of known eelers. The protocols for each survey type are described below.

2.3.1.1 On-site surveys

On-site creel surveys were planned to cover the period from mid-January through May, when eeling has historically occurred at the mouth of the Eel River. However, 2014 surveys were only conducted from late January through March in 2014, since all known eeling effort for the year ceased by April due to lack of capture. On-site surveys were conducted when weather, river flow, and wave conditions were safe and suitable for eeling, with a goal of performing two surveys per week. In 2014, however, pilot creel surveys were sporadic and generally occurred more frequently during periods when eelers were known to be putting in considerable effort. Surveys were conducted during the daytime and timed to coincide with the outgoing tide through the low slack tide, when most effort is known to occur based on preliminary interviews (Stillwater Sciences 2010).

On-site creel surveys were conducted by one or more WNRD staff (creelers) at the mouth of the Eel River, which they accessed from the north using a four-wheel-drive vehicle. The creel survey was designed to collect harvest and fishing effort data efficiently and effectively without imposing exceedingly on survey participants. If eelers were present and actively eeling, creelers made contact and began informing them about the creel survey. An informational flyer describing the creel survey was distributed when deemed appropriate. Creelers only attempted to interview people who appeared open and willing to engage in conversation about the creel survey and avoided asking eelers to wait to be interviewed. In some cases, creelers asked an eeler to check in with them when done eeling so that they could be interviewed immediately prior to their departure. If no or few eelers were present, or if the creel survey interviews and data collection were complete, creelers would spend time eeling. Periods spent eeling by creelers were treated similarly to other interviews, with all data recorded on a creel survey datasheet.

Effort and harvest

Creelers recorded the following general information for each date creel surveys were conducted:

- Survey date
- Location
- Crew member(s)
- Weather conditions—brief description of cloud cover and wind conditions
- River/surf conditions—brief description of water visibility and surf height
- Start time—time survey crew arrives at site
- Stop time—time survey crew is ready to leave site
- Number of eelers present—tally of total number of people observed actively eeling during survey
- Number of eelers surveyed—total number of people interviewed

For each interview, creelers then asked the following questions, indicating whether data pertained to an individual or group of eelers (when relevant):

- How many hours were spent eeling today?
- How many eels were harvested today?
- What capture method was used?
- How many eels were observed today and not captured?
- How many days have you been eeling this season?

- Average number of hours per day?

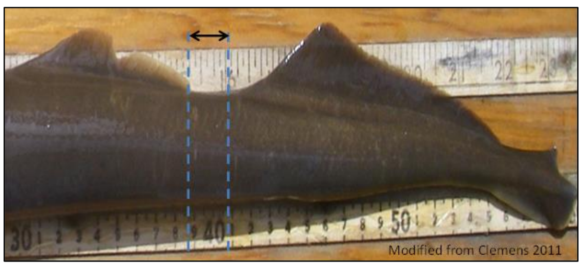
- How many eels have you captured this season (or since last surveyed)?
- Do you have any other notes or observations from your time eeling (e.g., ecological, cultural, historical)?
- During what part of the tide cycle do you typically eel?
- Do you ever eel at night?

The intent of the latter two questions was to collect additional information on potential eeling effort during times outside of those being focused on for the 2014 creel survey to inform whether survey timing should be modified for future surveys.

Biological data

If an interview was well-received and Pacific lampreys were captured, the crew inquired whether biological data could be collected from harvested eels. If an eeler approved, the following data were collected from as many lampreys as possible.

- Fish length—total length in millimeters
- Inter-dorsal length—length between first and second dorsal fins in millimeters (see picture below), also referred to as the "dorsal gap" by Clemens (2011).



- Fish weight—weight in grams (using hanging scale with thin mesh bag)
- Sex (male, female, or unknown)—where possible fish was cut open and male or female gonads identified.
- A photograph (with ruler for scale) to document condition, size, and any distinguishing features of individuals.

2.3.1.2 Phone interviews

Periodic phone interviews were planned as part of 2014 creel surveys to help understand total effort expended by regular eelers and get a coarse estimate of the total lamprey harvest for the season. Phone interviews were also designed to collect supplemental information to help refine future on-site and phone surveys. Phone interviews focused on individuals who were pre-selected because they are known to be frequent eelers and likely constitute a large proportion of the eeling effort and harvest. Phone interview questions were developed to provide similar data as the field creel surveys, with minor variations in the questions. Phone interviews were planned to occur two-to-three times during the season (e.g., February, April, and June).

The following questions were included on the phone interview form:

1. How many days have you been eeling this season, or since the last phone interview?

2. How many hours did you typically spend eeling each time?
3. How many eels have you harvested this season, or since the last interview?
4. How many eels have you observed and not captured this season, or since the last phone interview?
5. What capture method was used to harvest eels (eel hook, net, trap, other)?
6. Have you observed others eeling at the mouth of the Eel River this season?
7. If so, approximately how many?
8. Have you been eeling in locations other than the mouth of the Eel River this season?
9. On what dates were the earliest, latest, and peak number of eels observed and/or captured this season thus far?
10. During what part of the tide cycle do you typically eel?
11. Do you ever eel at night?
12. Do you have other comments or observations you would like to share about ecological, cultural, or historical elements of the eel population or fishery on the lower Eel River?

2.3.2 Results

2.3.2.1 On-site surveys

Effort and harvest

Fifteen on-site creel interviews were conducted at the Eel River mouth over the course of 13 survey dates between 29 January and 28 March 2014 (Table 2-14). Surveys were not consistently conducted on a bi-weekly interval as planned, but occurred sporadically during the survey period, generally based on when the primary creeler was available, tidal conditions were favorable, and eeling effort was known to be occurring based on word of mouth. Within the survey period, the number of eelers present during creel surveys varied between two and eight (Table 2-14, Figure 2-19). Total eeling effort (sum of effort by each individual present) ranged from 2.5 hrs to 30 hrs per survey date. Eeling effort was sporadic, but generally concentrated in the month of February (Figure 2-19).

On-site creel surveys documented a total of 88 Pacific lampreys being harvested at the Eel River mouth during the 2014 survey period (Table 2-14). The number of Pacific lampreys harvested on a survey date ranged from 0 to 29. An additional 115 Pacific lamprey were observed but not captured by eelers on the dates surveys were conducted (Table 2-14, Figure 2-20). Catch-per-unit-effort (CPUE) over all thirteen survey dates combined in 2014 was 0.6 fish/hr, peaking at 1.6 fish/hr on 13 February (Table 2-14, Figure 2-20).

Creeler observations and response to surveys indicated that, excluding 9 February when eeling was attempted on an incoming tide, all known effort in 2014 occurred during the outgoing tide, typically the latter half of the tidal cycle until low tide. Except for one attempt on the night of 23 February, all eeling was conducted during daytime. Notably, all but 1 of the 29 lampreys from 23 February were captured by a separate group that eeled during the morning outgoing tide. All lampreys were collected with eel hooks, with the exception of one captured by hand.

Table 2-14. Summary of eeling effort and Pacific lamprey capture at the mouth of the Eel River based on pilot creel surveys conducted in winter 2014.

Survey date	Number of eelers present	Number of creel interviews conducted	Eeling effort (person hours)	Number of Pacific lamprey captured	Number observed but not captured	CPUE (fish/hr)
1/29/2014	5	1	12.5	0	0	0.00
2/9/2014	3	1	3.0	0	0	0.00
2/13/2014	4	1	10.0	16	56	1.60
2/14/2014	8	2	19.25	17	14	0.88
2/15/2014[1]	3	0	0	0	0	--
2/19/2014	2	1	2.5	0	2	0.00
2/23/2014	7	2	30.0	29	--[2]	0.97
2/24/2014	4	2	13.5	6	24	0.44
2/25/2014	8	1	26.0	9	5	0.35
3/12/2014	2	1	8.0	4	12	0.50
3/26/2014	3	1	6.0	0	0	0.00
3/27/2014	2	1	5.0	2	2	0.40
3/28/2014	2	1	8.0	5	0	0.63
Total	--	**15**	**146.75**	**88**	**115**	**0.60**

[1] A creeler was on site, but conditions were not suitable for eeling and no effort was expended on this date.
[2] Data for one of the groups interviewed on 2/23/14 was word-of-mouth from the morning outgoing tide and data on number observed but not captured was not provided.

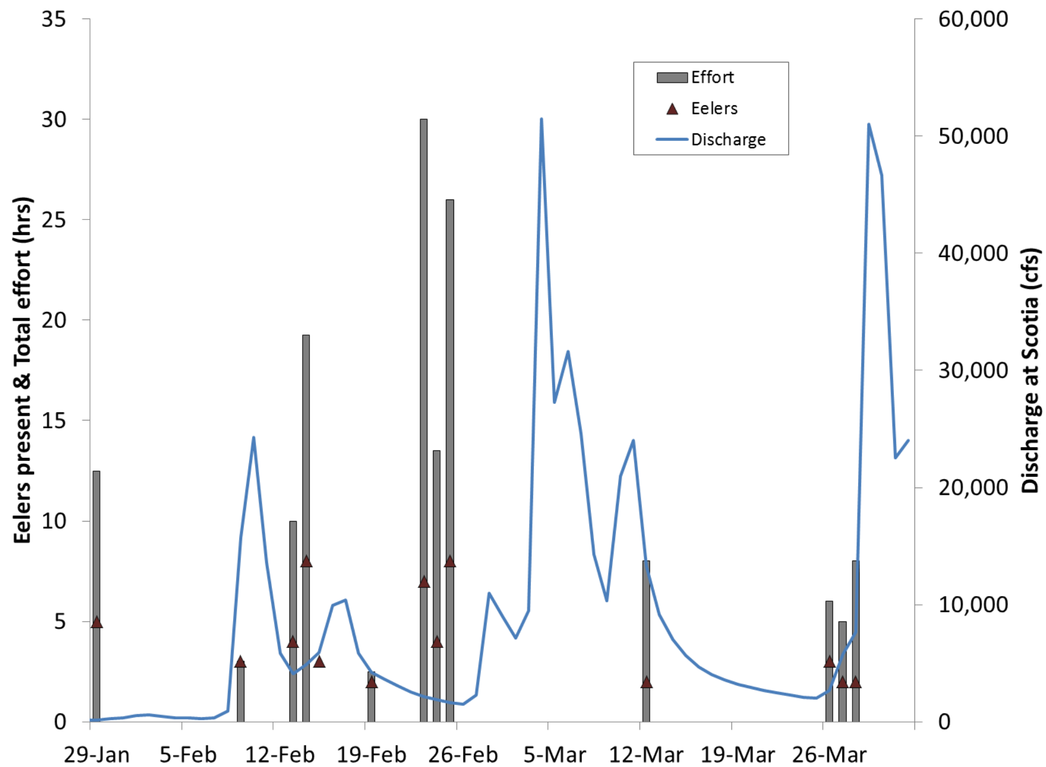


Figure 2-19. Number of eelers present, total eeling effort on dates surveyed, and discharge at the Scotia gage (USGS gage # 11477000).

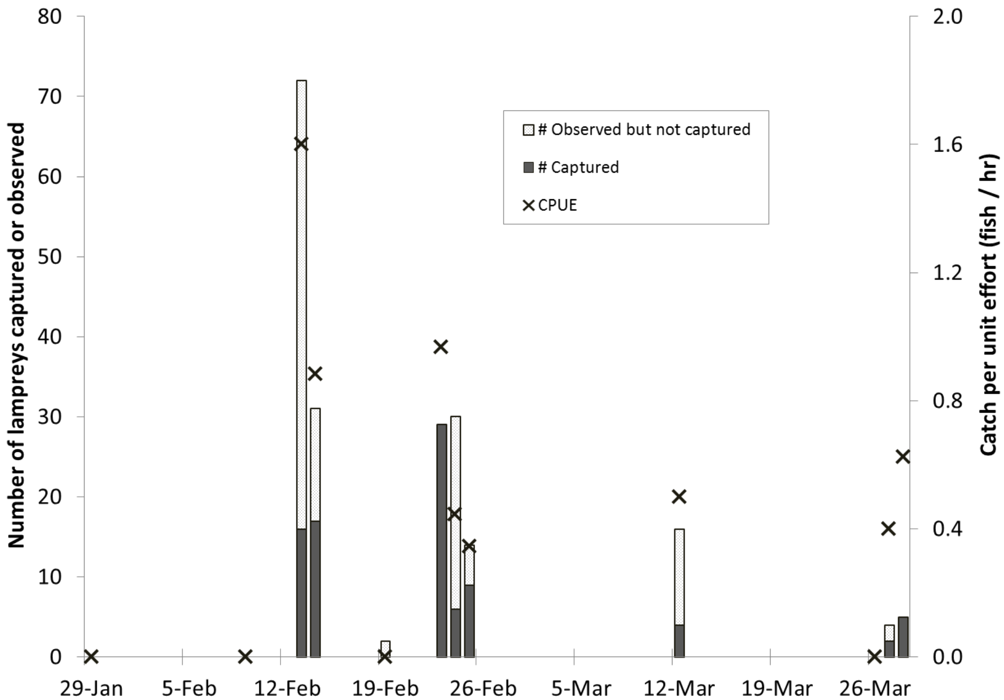


Figure 2-20. Number of Pacific lampreys captured or observed at the mouth of Eel River and catch-per-unit-effort on each survey date for which effort was expended.

Biological data

Length and weight measurements from 40 Pacific lampreys were recorded during creel surveys at the Eel River mouth (Table 2-15). The sex ratio of the 32 fish whose sex could be determined was approximately 1:1. Sex of the remaining eight fish examined could not be determined because they were not permitted to be cut open. On average, females were longer and heavier than males (Table 2-15), but these differences were not statistically significant for length (*two-sample t-test*; df = 30, $P = 0.2267$) or weight ($P = 0.3457$). Mean inter-dorsal length was also larger for females, but while suggestive, this difference was not significant at the 95% confidence level ($P = 0.0726$).

Table 2-15. Summary of Pacific lamprey biological data collected during 2014 creel surveys at the Eel River mouth.

Sex	N	Total length (mm)			Inter-dorsal length (mm)			Body weight (g)		
		Mean (SE)	Min	Max	Mean (SE)	Min	Max	Mean (SE)	Min	Max
F	15	623.7 (6.5)	585	670	42.6 (1.2)	35	50	454.3 (24.3)	265	585
M	17	611.3 (7.9)	560	655	38.9 (1.5)	27	47	426.8 (16.5)	310	530
UK	8	628.3 (7.8)	605	667	37.5 (2.5)	30	45	443.1 (17.0)	380	515
Total	**40**	**619.4 (4.4)**	**560**	**670**	**40.0 (1.0)**	**27**	**50**	**440.4 (11.9)**	**265**	**585**

2.3.2.2 Phone interviews

One-time phone interviews were conducted with three regular Wiyot eelers, all in early March 2014 (Table 2-16) and prior to the last documented eeling effort in late March based on on-site creel surveys (Table 2-14). Phone interviews, along with known eeling effort documented by on-site creel surveys, indicated that individual respondents eeled between 5 and 8 days during the 2014 season and captured between 13 and 34 Pacific lampreys during that time, all with eel hooks. Two of the respondents also observed relatively large numbers of migrating lampreys that were not captured. The earliest and latest reported captures were on 13 February and 6 March, respectively; however on-site surveys documented all respondents eeling in later March after the phone interviews were conducted. Phone interviews also indicated that all effort was conducted during the outgoing tide, during the day. In addition, surveys revealed that at least 17 individuals eeled at the mouth of the Eel during winter 2014, including some individuals from other local Native American tribes (e.g., Yurok and Hoopa tribes). Finally, information from phone interviews revealed that considerable effort by the respondents—not documented by on-site creel surveys—occurred in late February and early March (Tables 2-14 and 2-16).

Table 2-16. Summary of responses to phone interview questions by regular Wiyot eelers.

Question	Respondent 1	Respondent 2	Respondent 3
Interview date	3/6/2014	3/10/2014	3/10/2014
Days eeled in season?[1]	8	5	7
Lampreys harvested in season?[2]	25	13	34
Seen but not captured?	50–60	5	100+
Primary capture method?	eel hook	eel hook	eel hook
Effort at locations other than Eel River mouth?	No	No	No
Earliest capture?	2/13/2014	no response	2/14/2014
Peak capture?	2/13/2014	no response	2/23/2014
Latest captured?[3]	3/1/2014[3]	no response	3/6/2014[3]
Tidal cycle typically eeled?	last half of outgoing	outgoing	outgoing
Eel at night?	no	no	no
Number of other eelers observed in season?	16–17	several	10+
Other relevant information provided	Eeled at least 4 days (2/26-3/1) and report capturing of 10 lampreys and missing 15 when creeler was not present. Observed non-Wiyot eelers capturing 10 or more on 3/1.	none	Indicated eeling at night is not possible due to gate to beach access. Reported observing a non-Wiyot eeler.

[1] Includes number of days indicated by respondent on the date of the phone interview plus known effort following the phone interview based on on-site creel surveys.
[2] Includes lampreys harvested by individual based on the phone interview and subsequent on-site creel surveys of each respondent.
[3] Subsequent on-site interviews indicated that all respondents captured eels during the last week of March.

2.3.3 Discussion

The pilot creel surveys conducted in winter 2014 were successful, both by collecting valuable data on Pacific lamprey harvest patterns and biology, and by informing sampling timing and protocol refinements for improving future surveys (Section 3). On-site creel surveys documented the capture and harvest of 88 Pacific lampreys by eelers at the mouth of the Eel River. Since, as documented by phone interviews, there was additional eeling effort on days when creel surveys were not conducted, this value should be considered a minimum harvest estimate for the season. CPUE estimates from 2014 pilot surveys provide a metric of relative abundance of the 2014 run that can be contrasted with future years. However, due to the sporadic timing of 2014 surveys, strong conclusions about the strength of the Pacific lamprey run should not be drawn from 2014 data.

Data from phone interviews were of limited utility due to the small number of interviews conducted. However, these interviews provided information that was useful for interpreting on-site creel survey data and informing improvements to future creel surveys. For example, phone interviews indicated that additional eeling effort occurred and lampreys were captured on days when the creeler was not present. These pilot interviews also helped understand necessary protocol changes required to improve the success and value of phone interviews in future years of monitoring. These changes are discussed in Section 3.5.

Finally, data on sex ratio, total and inter-dorsal length, and weight of Pacific lampreys captured by eelers are valuable for understanding the basic biology of the species in the Eel River and how it compares with other river systems.

3 LONG-TERM MONITORING RECOMMENDATIONS

This section describes a multi-life-stage Pacific lamprey long-term monitoring program for the WNRD to implement in the lower Eel River study area. Results and lessons-learned from pilot lamprey monitoring surveys (Section 2) were used to refine field protocols and develop recommendations for effective monitoring of relative abundance and distribution of ammocoetes, spawning adults, and migratory adults. This section can effectively be viewed as a monitoring handbook, a reference to guide future lamprey monitoring activities by the WNRD. Section 3.1 establishes the goals of the monitoring program, describes program constraints, and explains the need for applying an adaptive monitoring approach. Sections 3.2–3.5 detail site selection and spatial considerations, timing and periodicity, survey protocols, and considerations for analysis and reporting for each element of the monitoring program. Each of these factors are also outlined in tabular format in Appendix C for easy reference. Section 3.6 outlines considerations related to data management and quality control.

3.1 Monitoring Goals and Programmatic Considerations

The primary goal of the Wiyot Tribe's monitoring program is to monitor trends in abundance and distribution of the Pacific lamprey population within the lower Eel River basin study area. A secondary monitoring goal is to improve understanding of the basic biology, life history, and habitat availability of the species to better understand factors limiting abundance and distribution of each life stage. Since there is currently no systematic monitoring of the species in the Eel River basin, or throughout much of its range, achieving these goals will help the Wiyot Tribe and local and regional co-managers more effectively manage, conserve, and restore this important species.

Collecting regular monitoring data and improving understanding of limiting factors are also essential components of the ongoing, range-wide Pacific Lamprey Conservation Initiative (Wang and Schaller 2015).

The overall study area for long-term monitoring will be the same as that of the pilot surveys (Section 1.2, Figure 1-1), except that the study area for ammocoete index site surveys will be extended upstream to match the upper extent of the mainstem study reaches used for pilot spawning surveys (i.e., South Fork Eel River upstream to the East Branch, and Van Duzen River upstream to Golden Gate Bridge).

The ability of the WNRD to implement each element of the monitoring program annually will be largely contingent upon funding, but it is our intent to carry out monitoring indefinitely into the future to help track the lamprey population response to ongoing watershed recovery efforts and existing and future threats such as climate change. During each year when monitoring is conducted, a report summarizing annual results of each element will be produced. More extensive reports evaluating population trends and recommending necessary changes to the program under an adaptive monitoring process will be produced approximately every five years.

The recommended sampling design and scope-of-inference for each element of this monitoring program are restricted by the small staff size of the WNRD, as well as the limited and unpredictable funding available for Pacific lamprey monitoring in the Eel River. Moreover, the large, and in places, remote study area and the high percentage of private property make access difficult or impossible in significant portions of the study area, restricting the effective sampling frame for monitoring site selection. Finally, state permitting restrictions limit the number of study sites we are able to visit annually. Due to these and other constraints, we have opted to apply a non-randomly selected index site approach for monitoring relative abundance of Pacific lamprey ammocoetes and spawning adults, rather than a more probabilistic sampling approach (e.g., randomized site selection) that would provide more robust estimates and statistical certainty, but at a higher cost. If more regular and secure funding becomes available and access issues are resolved, index surveys may be transitioned to a more randomized sampling design through an adaptive monitoring process. Using an index site approach to monitor relative abundance relies on the assumption that population trends at index sites are representative of population trends in the stream reaches in which they are located.

We recommend applying an adaptive monitoring approach whereby annual survey effort and protocols are periodically evaluated and revised to reflect existing and future funding and other constraints to achieving monitoring goals. In developing recommendations for each monitoring element, we determined the approximate effort required (number of staff and days) based on number of sites and samples, sampling periodicity, and timing (Appendix C). These factors were adjusted to meet program goals and be compatible with existing WNRD funding and staffing constraints, but will be re-evaluated periodically through the adaptive monitoring process. In general, when sufficient funding is available, the number of sites surveyed and survey frequency will be expanded. In years when funding is limited, only higher-priority monitoring tasks may be carried out, and lower-priority index sites may be excluded. To the extent possible, any necessary changes to survey scope and frequency will be done in a way that allows annual measures of relative abundance to be compared with previous annual data for each stream in the study area. Factors specific to adaptive monitoring for each element of the monitoring program are discussed in more detail in the sections below.

3.2 Ammocoete Distribution

A key goal of the Wiyot monitoring program is to monitor changes in the spatial distribution of the Pacific lamprey population in the study area. Achieving this goal necessitates collecting data to inform both presence/absence and upper distribution of the species within each stream. Monitoring the ammocoete life stage is generally a more reliable way to evaluate Pacific lamprey distribution compared with monitoring spawning adults due to the typical year-round presence of multiple year-classes of ammocoetes, their greater abundance, long freshwater residence (4–7 years), and predicable use of easily sampled depositional habitats. The primary objectives of conducting ammocoete distribution surveys are to (1) continue expanding knowledge of the current distribution of Pacific lamprey in the study area, and (2) monitor changes in distribution over time as an indicator of population status.

3.2.1 Site selection and spatial considerations

Sites should be selected for distribution surveys from the list of streams developed for pilot surveys, excluding "unwadeable streams" (Appendix A). Each year, we recommend sampling as many of the remaining streams (those not sampled during 2013-14) as possible given staffing constraints and other monitoring priorities, until presence/absence of Pacific lamprey has been determined for all streams that can be accessed. Distribution surveys for wadeable streams categorized as "large" (drainage area > 100 km^2) should focus on determining the upper distribution of ammocoetes, since presence in these stream has generally already been determined. Where possible, upper distribution surveys should be done in tandem with planned presence/absence surveys of tributaries to these streams (i.e., sampling at the confluences of tributaries) to improve efficiency.

As with pilot surveys, presence/absence distribution surveys of streams categorized as "very small," "small," or "medium" should typically begin at a stream's confluence and continue upstream until one of the following applies:

- Pacific lampreys are definitively documented after surveying at least one 100-m channel segment.
- At least ten 100-m segments (1,000 m) of channel are surveyed and no Pacific lampreys are found.
- Approximately 10 non-adjacent highly suitable (Type I) ammocoete habitat patches with an area greater than 1 m^2 (10.8 ft^2) are sampled and no Pacific lampreys are found—and at least three complete 100-m segments of stream are surveyed.
- Access is limited due to safety concerns or private property.

Upper distribution surveys of streams categorized as "large" should begin just upstream of the upstream-most location that Pacific lampreys have been previously documented. If Pacific lampreys are not documented in the first 100-m segment sampled, crews should continue sampling following the guidelines described in the bullets above. If Pacific lampreys are still not documented (after surveying either 1,000 m of channel or sampling 10 Type I habitat patches > 1 m^2), field crews should move downstream and initiate the sampling protocol at the confluence of the next downstream named tributary (listed in Appendix A). If Pacific lampreys are documented in the first 100-m segment, crews should move upstream and initiate the sampling protocol at the confluence of the next upstream named tributary. Crews should continue moving upstream, sampling at each tributary confluence until Pacific lamprey are no longer documented using the presence/absence guidelines described above.

3.2.2 Timing and periodicity

After establishing the baseline upper distribution for large streams and presence/absence in the smaller streams, we recommend re-visiting each stream on the sampling list once every 5 years, prioritizing larger streams if funding or staffing constraints arise. Note that streams selected for more regular relative abundance monitoring with index reach surveys (Section 3.3) can be excluded from periodic distribution surveys, since they will be sampled annually (unless they are categorized as large, in which case they should be sampled for upper distribution). We anticipate sampling approximately half of the accessible streams listed in Appendix A each year that distribution surveys are conducted (assuming that a considerable number of streams will not be safely accessible).

Distribution surveys should be consistently conducted during the dry season (July–October), and ideally each stream should be sampled in the same month it was previously sampled to allow for more meaningful comparison with previous surveys. Sampling during low flows is also expected to require less habitat area to sample and result in better visibility. Additionally, stream flows during the dry season are expected to limit ammocoete distribution. Conducting surveys during the dry season allows documentation of low stream flows or dry stream beds, and thus absence of ammocoetes can be attributed to lack of water, which is not possible when surveying during higher winter flows.

3.2.3 Survey protocols

Distribution surveys will generally be conducted using the same methods applied during pilot surveys: all suitable ammocoete habitat (both Type I and Type II) in selected reaches of study streams will be sampled with a backpack electrofisher at a constant rate (90 s/m^2) in 100-m stream segments until Pacific lamprey presence or absence has been adequately established as detailed in Section 2.1.1.

The following minor protocol changes are recommended moving forward:

- Measure and record stream flow at the beginning of each survey to help understand how wetted habitat area and ammocoete distribution varies with stream flow. Refer to Harrelson et al. (1994) for detailed methods for measuring stream flow.
- Enumerate and measure ammocoetes captured in each habitat patch separately, instead of lumping ammocoetes captured in each 100-m reach segment. This step is recommended to allow finer-scale analysis of habitat factors potentially explaining ammocoete presence (and relative abundance) such as LWD presence and sediment depth. This change will require minor changes to data sheets used during pilot surveys.
- Enumerate and measure all ammocoetes, including those that cannot be identified to species (<60 mm). Individuals clearly <25 mm in length can be tallied (and not measured if necessary), using "YOY" (young-of-the-year) to designate life stage.
- Attempt to use consistent staff for electrofishing and netting to control for potential differences in operator capture efficiency.

3.2.4 Metrics, analysis, and reporting

The primary metrics used to assess and report on changes in Pacific lamprey distribution should be (1) species presence/absence within streams categorized as "very small, small, or medium" and (2) upper distribution within streams categorized as "large" in Appendix A.

Secondary metrics to assess and report are measures of ammocoete relative abundance and habitat availability within survey reaches. The use of consistent methods and sample effort during distribution surveys will allow for coarse estimates of relative abundance (fish/100 m), which can be compared with results of previous distribution surveys conducted in the same reaches. The primary metric for evaluating and reporting relative abundance should be the number of ammocoetes of each species >60 mm/100 m of channel surveyed, since these larger individuals can be reliably identified to species and have a greater overall importance to the population. However, smaller individuals should be captured and measured as described above to help with general understanding of population dynamics (e.g., relative success of annual ammocoete recruitment for all species combined) and provide data on prevalence of younger age classes at different locations. We also recommend reporting basic length-frequency data for captured ammocoetes, as well as the number of eyed ammocoetes (transforming or macrophthalmia) captured. As discussed in Section 2.1.3, ammocoete surveys were designed to target preferred ammocoete habitat, but not necessarily preferred habitat of transforming ammocoetes, and thus survey results should not be used to draw strong conclusions about distribution or relative abundance for this life stage.

The following measured habitat metrics that may affect distribution should also be summarized to help explain patterns in ammocoete distribution and relative abundance:

- Number of suitable habitat patches in each survey reach by Type I and Type II categories.
- Area of suitable habitat in each survey reach and per length of channel surveyed.
- Number of qualifying LWD pieces in each survey reach and per length of channel surveyed.
- Stream flow and temperature for each survey reach from point measurements.
- Annual stream flow and water temperature patterns for the larger study area (e.g., Table 2-6).

3.3 Ammocoete Relative Abundance

Monitoring trends in abundance of the Pacific lamprey population in streams within the study area is a key goal of the monitoring program. Tracking changes in abundance of the ammocoete life stage is critical for achieving this goal, since the number of ammocoetes in a watershed is expected to be an important determinant of the number of adults that return—both in the present (through release of pheromone-like migratory attractants) and future (through greater production of macrophthalmia and thus adults) (Stillwater Sciences 2014a).

We recommend monitoring ammocoete relative abundance through regular sampling of index reaches (in small to medium-sized wadeable streams) and index sites (in large and unwadeable streams). Using the index approach to monitor relative ammocoete abundance for each stream relies on the assumption that population trends at index sites and reaches are representative of population trends in the streams they are located in, at least within the study area. As more ammocoete monitoring data are collected, the veracity of this assumption can be assessed by comparing observed temporal trends in relative abundance at individual index sites with observed trends across all sites in each study stream. Considerations for selecting and sampling index reaches and index sites are addressed below.

3.3.1 Site selection and spatial considerations

3.3.1.1 Index reaches in wadeable streams

We recommend monitoring relative abundance of ammocoetes in select index reaches in easily accessible and wadeable streams categorized as small or medium where Pacific lamprey have been previously documented (Appendix A). Index reaches may also be selected in certain streams where Pacific lampreys were not documented but which have high habitat potential or interest to the Tribe (e.g., Strongs Creek). We recommend regular monitoring of index reaches in a minimum of 10 streams spread out across the study area. Streams to consider for index reach surveys include Price Creek, Strongs Creek, Bear Creek, Booths Run, Shaw Creek, South Fork Yager Creek, Grizzly Creek, Root Creek, Squaw Creek, and Cuneo Creek. As more information on Pacific lamprey presence in small and medium-sized streams is gained, additional streams may be added for index reach monitoring if staffing and funding allow.

Within each stream selected, 100–300 m of channel containing a relatively large area of suitable ammocoete habitat (based on pilot distribution and habitat surveys and additional pre-survey scouting as required) should be selected for index reaches. In some cases, the exact reach segments sampled during pilot distribution surveys will be appropriate index reaches; however segments containing little to no habitat should not be considered for long-term monitoring. For some streams, it may be necessary to select index reaches outside the boundaries of pilot distribution survey reaches.

3.3.1.2 Index sites in large and unwadeable streams

Using a backpack electrofisher to characterize relative abundance of ammocoetes in large or unwadeable streams has numerous challenges. Depth limitations of the electrofisher require that sampling occur in water less than approximately 1 m deep, often restricting samples to stream margins. Patches of fine-sediment habitat can also be very large (>100 m^2) and not logistically feasible to sample in their entirety. Despite these limitations, unwadeable streams should not be discounted for monitoring, as the large areas of suitable ammocoete habitat present there (relative to smaller streams) mean they likely play a critical role in population dynamics for the larger watershed. For these reasons, we recommend selecting and regularly sampling discrete index sites to monitor relative abundance of Pacific lamprey ammocoetes in the large and unwadeable streams in the study area. Generally these sites should encompass or be located within a relatively large and contiguous Type I habitat patch, a subset of which will be sampled to characterize ammocoete density at the site.

We recommend selecting a minimum of three sites each in the lower Eel, Van Duzen, and South Fork Eel rivers (“unwadeable”), and three sites each in Yager, Lawrence, Larabee, and Bull creeks (“large”). However, in years where staff schedules and budget allow additional sites should be added. Within these streams, index sites should be spatially stratified (e.g., spread relatively evenly over lower, middle, upper reaches of each stream within the study area boundary), taking into account location relative to major tributaries. For example, in the mainstem Eel River, select one site downstream of the Van Duzen River, one site between the Van Duzen River and Larabee Creek, and one site between Larabee Creek and the end of the study area at the South Fork Eel River confluence. Where possible, index sites should be located in areas where the ammocoete habitat patch is expected to be relatively stable over time (e.g., associated with more permanent features such as bedrock, established side-channel, or a river bend).

Selected index sites should be between approximately 30 m^2 and 300 m^2 in area, depending on stream size and the area of suitable ammocoete habitat present. When a habitat patch at a selected location is longer than approximately 50 m (from downstream to upstream), as is the case for many patches in the lower Eel, Van Duzen, and South Fork Eel rivers, a 50-m section should be selected as the index site—preferably in the approximate middle of suitable habitat patch. In these unwadeable streams, the maximum width of the index site boundary will often be dictated by water depth, since it is not feasible to sample in water >1 m deep. The minimum width of selected index sites in these unwadeable streams should be no less than 2 m. The process for delineating patch boundaries at index sites in unwadeable streams is described in more detail below (Section 3.3.3.2).

For the generally wadeable large streams (e.g., Bull and Lawrence creeks), index sites should typically encompass an entire Type I habitat patch with an area greater than approximately 30 m^2 and have a minimum width of 1 m (to allow placement of the sampling frame).

Within each index site, we recommend sampling 15 1 m^2 quadrats that are distributed evenly from upstream to downstream and left bank to right bank. Power analyses of data collected during pilot surveys indicate that sampling the same 15 quadrats during each monitoring event is sufficient to statistically detect changes in mean densities over time of 2 fish/m^2 and 1 fish/m^2 at Eel and Van Duzen river sites, respectively (Section 2.1.2.2). While sampling a greater number of quadrats would provide more confidence in detecting smaller changes in relative abundance, it would take considerably more effort, thus decreasing the number of index sites that could be sampled each year for a given cost/effort. Sampling a greater number of index sites will help control for variation in the distribution and abundance of ammocoetes across a larger scale and increase the ability to detect changes in relative abundance of the overall ammocoete population in each stream.

3.3.2 Timing and periodicity

3.3.2.1 Index reaches in wadeable streams

We recommend sampling of the ammocoete population in selected index reaches on an annual basis. Reaches should be sampled once each year during the dry season (July–October), and ideally each reach should be sampled in the same month it was previously sampled to limit potential effects of varying stream flow and habitat conditions and allow for more meaningful comparisons of relative abundance.

In the event that available funding does not allow sampling in a given year, we recommend sampling index sites as regularly as feasible, which will still allow detection of substantial changes in relative abundance over time. Index reaches should be categorized as either higher or lower priority (based on drainage area), including at least two high priority reaches in the Eel, Van Duzen, and Bull Creek watersheds. In years when funding and/or staffing constraints preclude sampling all index reaches, only higher priority index reaches could be sampled.

3.3.2.2 Index sites in large and unwadeable streams

As with index reaches, we recommend sampling each index site once per year during the dry season (July–October), and ideally in the same month previously sampled. If funding or staffing constraints arise, we recommend prioritizing sampling index sites over index reaches.

3.3.3 Survey protocols

3.3.3.1 Index reaches in wadeable streams

Methods applied to estimate ammocoete relative abundance in index reaches should generally follow those described for ammocoete distribution surveys (Sections 2.1.1.1 and 3.2.3), except that a discrete length of stream will be sampled regardless of whether Pacific lamprey ammocoetes are detected. We also recommend collecting data to characterize availability of suitable ammocoete habitat, large wood abundance, stream flow, and temperature as described for distribution surveys. As with all surveys, consistency in methodology between years is crucial for index reach surveys to allow for meaningful comparison with previous years and analysis of trends.

3.3.3.2 Index sites in large and unwadeable streams

Methods used for long-term monitoring of relative abundance at index sites in large and unwadeable streams, should generally follow those applied during pilot sampling of index sites (Section 2.1.1.2), while implementing the following modifications:

- The first year each index site is sampled, monument the site by driving a rebar stake into the bank adjacent to each site. This monument will be used to locate the site and as a permanent reference to help locate site boundaries and sample quadrats for long-term monitoring. Ideally, the monument should be placed in a protected location at an elevation greater than bankfull stage.
- Mark the boundaries of each index site to be sampled using the polygon feature of a differential global positioning system (DGPS) unit set to 0.5 m post-processed accuracy-based logging, which prevents logging of features that do not meet the accuracy threshold. Post-process these GPS data using differential correction to improve accuracy.
- Attempt to sample the exact same 1-m^2 quadrats each year due to greater statistical power offered by a *paired two-sample t-test* (Section 2.1.2.2).
- If real-time GPS accuracy estimates are <1 m at an index site, record GPS coordinates in the center of each sample quadrat to use as the basis for finding and sampling the same quadrats in subsequent years.
- If real-time GPS accuracy is >1 m, sample quadrats should be relocated using the gridded site diagram and measuring distances relative to the site monument (re-bar stake) and other landmarks.
- Estimate the area of Type I habitat within the boundaries of selected index sites (this can be calculated from the polygon collected with GPS). This step will allow for coarse estimates of the number of ammocoetes present at each site based on mean density in sampled quadrats.
  - In cases where the area of suitable habitat extends beyond the index site boundary (e.g., longer than 50 m or into water deeper than 1 m), attempt to estimate the entire area of the wetted habitat patch (index site area plus area of contiguous Type I habitat). If feasible, use the GPS polygon feature for these estimates. These estimates will aid in interpretation of results by helping to understand how summer habitat availability changes over time and whether observed changes in ammocoete density (fish/m^2) at a given site could be related to changes in suitable habitat area at that location.

- Sample 15 1 m^2 quadrats at each site (instead of the 30 sampled during pilot surveys), separated by at least 1 m and distributed evenly from downstream to upstream and from the bank edge to the thalweg edge of the site.
- Do not split each index site into lower, middle, and upper segments as was done during pilot surveys.
- In each sample quadrat, attempt to capture and measure all ammocoetes >25 mm in length (older than YOY), prioritizing individuals that appear to be >60 mm if large numbers of ammocoetes simultaneously emerge from the substrate. Capture and measure as many YOY ammocoetes as possible, while still capturing all older individuals.
- For each quadrat, attempt to tally individuals observed but not captured by the following size classes: >25 mm, 26–59 mm, and >60 mm.
- Use consistent methods and conventions for capturing and recording fish across all quadrats and sites.
- Attempt to use consistent e-fishers and netters to control for potential differences in operator capture efficiency.
- For each index site, record stream flow during the survey (from nearest USGS gage) to ensure sampling occurs at consistent flows across years and help interpret results.

3.3.4 Metrics, analysis, and reporting

3.3.4.1 Index reaches in wadeable streams

The primary metric used to evaluate ammocoete relative abundance in index reaches will be number of ammocoetes of each species >60 mm /100 m of channel surveyed (fish /100 m). As with distribution surveys, numbers of individuals captured <60 mm in length should also be summarized to describe length-frequency and age structure and understand population dynamics. Number of eyed ammocoetes (transforming or macrophthalmia) captured should also be summarized for each index reach. Reporting monitoring results should focus on Pacific lamprey, but species composition (*Entosphenus:Lampetra*) at each site and how it changes over time should also be summarized.

Analysis of trends in relative abundance over time for each index reach and across all index reaches can be explored using scatter plots and linear regression models. In general, linear regressions should be used to evaluate the hypothesis that Pacific lamprey abundance is decreasing or increasing with time in a linear fashion. Selecting exact statistical methods and necessary data transformations for trend analysis will require careful assessment of future data sets and evaluation of key assumptions (i.e., statistical independence of error, constant variance, and normal distribution of error).

For each index reach, measured habitat metrics that could influence relative abundance should also be summarized and reported, including:

- Number of suitable habitat patches in each index reach by Type I and Type II categories
- Area of suitable habitat in index reach and per length of channel surveyed
- Number of LWD pieces in index reach and per length of channel surveyed
- Stream flow and temperature for each survey reach from point measurements
- Annual stream flow and water temperature patterns for the larger study area

Relationships between these variables and ammocoete relative abundance within a site and across index reaches can be explored with various statistical models, including regression and ANOVA analyses.

3.3.4.2 Index sites in large and unwadeable streams

The primary metric for monitoring changes in relative abundance of Pacific lamprey ammocoetes at index sites is mean density of ammocoete >60 mm in length (fish/m^2). If index surveys are conducted by sampling the exact same quadrats every time a site is surveyed, then statistical comparisons of differences in mean density at a site between two years can be done using a *paired t-test*. If it is infeasible to sample the exact same quadrats (or if quadrats were randomly selected), comparisons would be done using a *two-sample t-test*, which requires more samples per site to detect the same differences in density (Section 2.1.2.2). A *two-sample t-test* would also be used for comparing differences in mean density between two sites (or two streams) within a year, but this is of secondary importance compared with evaluating changes at index sites (or across all sites in a stream) over time. Changes in ammocoete density across all sites in each stream can be evaluated by pooling data across all sites and using a *two-sample t-test* to detect changes between years. As described above for index reaches, trends in relative abundance of ammocoetes at index sites (and within each stream) across multiple years can be assessed using scatter plots and linear regression models.

Secondary monitoring metrics to consider reporting and discussing for each index site and stream include:

- Minimum and maximum ammocoete densities observed in sample quadrats,
- Histograms displaying observed densities,
- Mean length of ammocoetes and length frequency histograms,
- Species composition (*Entosphenus*:*Lampetra*), and
- Area of wetted Type I habitat at location of index site (index site area plus area of suitable habitat that is contiguous with site).

Finally, we recommend conducting additional analyses exploring the relationships between ammocoete density and measured habitat variables in each stream where index sites are sampled. Such analyses will help build upon and substantiate findings from analysis of pilot data (Sections 2.1.2.2 and 2.1.3.2 and Appendix B) and improve interpretation of results and understanding of ammocoete ecology.

3.4 Spawning Adult Relative Abundance and Timing

Monitoring trends in abundance of the Pacific lamprey spawning population is an important component of a multi-life-stage monitoring program. We recommend monitoring relative abundance of spawning in the study area through annual surveys conducted in index reaches in wadeable streams and spatially stratified index sites in unwadeable streams. Due to the small numbers of Pacific lamprey spawning adults and carcasses observed during pilot spawning surveys, long-term monitoring will focus on redd counts. Because of their relative permanence and higher observable numbers compared with adults, redds are generally a more suitable metric for detecting and monitoring spawning activity in streams with low population densities (Brumo et al. 2009). While much uncertainty remains in exactly how Pacific lamprey redd counts relate to the number of spawning adult lamprey present in a given stream, we believe that redd counts are a viable measure of spawning abundance, since they have been shown to be highly correlated with counts of spawning adults (Brumo et al. 2009) and are universally used to monitor salmonid populations in similar environments (e.g., Gallagher and Gallagher 2005).

As with ammocoete surveys, using the index approach to monitor abundance of spawning stage lampreys relies on the assumption that population trends at index sites and reaches are representative of population trends in the streams they are located in. Research in other largely alluvial river systems supports this assumption. For example, in the South Fork Coquille River, Brumo et al. (2009) found that weekly indices of spawning activity in a single spawning area, 1–2 km sub-reaches, and an entire 9 km study reach were highly correlated throughout two spawning seasons. Similarly, in Freshwater Creek, redd density (redds/km) was moderately to highly correlated amongst 2–3 km sub-reaches and the entire 10-km study reach across 5 years of spawning surveys (Stillwater Sciences et al. 2016). For tributary streams composed entirely of alluvial underlying geology in the Willamette River basin, Mayfield et al. (2014) found that Pacific lamprey redds were relatively clumped at scales smaller than about 0.5 km, but there was minimal clumping at larger scales.

Considerations for selecting and surveying index reaches in wadeable streams and index sites in unwadeable streams for long-term monitoring of spawning abundance in the Eel River study area are presented below.

3.4.1 Site selection and spatial considerations

3.4.1.1 Wadeable streams

We recommend continuing to conduct regular spawning surveys in the same approximately 1.5–2.5 km index reaches surveyed in Lawrence and Bull creeks during 2014 pilot surveys (Table 2-11). These streams were selected for more intensive long-term monitoring because they are easily accessible, relatively close to the Table Bluff Reservation, and small enough to easily wade but large enough to support significant numbers of spawning Pacific lampreys. Additionally, substantial instream and upslope restoration projects are underway or planned in both watersheds, providing an opportunity to monitor lamprey population and habitat responses to these actions.

3.4.1.2 Unwadeable streams

We recommend conducting Pacific lamprey redd counts across a network of spatially stratified index sites selected in mainstem reaches of the lower Eel, Van Duzen, and South Fork Eel rivers within the study area (Figure 1-1). Rather than repeating pilot surveys, where two 5–6 km index reaches were surveyed per stream, we recommend surveying a minimum of one index site every eight km (5 mi) of channel within the study area. This equates to eight sites each in the Eel and South Fork Eel rivers and five sites in the Van Duzen River (within the mainstem study area). In general, sites should be evenly spaced while taking into account ease-of-access and location relative to major tributaries.

Each index site selected should encompass a discrete, high-quality spawning area, such as a pool tailout or low-gradient riffle with moderate water velocities and dominant substrate sizes ranging from approximately 10 mm to 100 mm. Upstream and downstream site boundaries should be defined by lack of suitable spawning habitat (e.g., slow water with substrate too fine for spawning on upstream end and higher gradient riffle with substrate too large for spawning on downstream end). Index site boundaries should be flagged and GPS coordinates recorded to ensure they can be found in subsequent survey years. Results of 2014 pilot surveys should be used inform selection of high quality index sites in the reaches surveyed. While the overall length of channel covered by surveying 5–8 index sites per stream will be considerably less than surveying two longer reaches, this spatially stratified approach is expected to provide sufficient indication of overall trends in spawning abundance across the mainstem study area with less overall effort (driving to easy-to-access locations rather than having to launch boats and shuttle vehicles).

3.4.2 Timing and periodicity

3.4.2.1 Wadeable streams

For long-term monitoring, we recommend conducting annual spawning surveys of Bull Creek and Lawrence Creek index reaches on a bi-weekly basis from April through June. In years where funding and staffing constraints arise, survey periodicity may need to be reduced to once per month, but a reduced number and frequency of surveys will provide a less robust understanding of seasonal patterns of spawning and will result in an underestimate of the total number of redds constructed during the spawning season due to difficulty in detecting older redds (see Figure 2-16). For this reason, results from years when monthly surveys are carried out should be compared cautiously with results from years when bi-weekly surveys are carried out. Nonetheless, monthly index reach surveys during the early, middle, and late portions of the core spawning period will help achieve the objective of detecting relatively larges changes in the annual spawning population.

3.4.2.2 Unwadeable streams

Annual peak spawning surveys of index sites in the Eel, Van Duzen, and South Fork Eel rivers should be conducted once per year between late May and mid-June, soon after the typical peak spawning period of mid-May. Each peak survey should be done in the same order and close to the same date as the previous year of monitoring. Using this peak count approach will result in missing a portion of redds constructed during the early and late ends of the spawning period, and thus should be considered a fairly coarse metric of annual relative abundance, aimed at documenting large changes in magnitude of annual mainstem spawning activity.

3.4.3 Survey protocols

3.4.3.1 Wadeable streams

Field protocols for monthly spawning surveys of Bull Creek and Lawrence Creek index reaches should follow those described for pilot bi-weekly surveys (Section 2.2.1.1). In addition, we recommend deploying continuous water temperature loggers annually near the mouth of each study stream to help evaluate the role of water temperature in spawning timing.

3.4.3.2 Unwadeable streams

Field protocols for index sites of unwadeable streams should generally follow those applied during pilot surveys of longer index reaches (Section 2.2.1.2), with the following changes or additional guidelines:

- When arriving at each site, the field crew should first discuss the most efficient approach for surveying all suitable spawning habitat and avoiding double-counting of redds.
- Ensure that there are a sufficient number of field crew members to adequately cover the width of the channel at each site. In most cases, a minimum of three to four snorkelers will

be required. As with pilot surveys, snorkelers should stand and wade as needed to help locate potential redds, which can then be inspected more closely via snorkeling.

- In addition to snorkelers, there should be one crew member, on foot or in a support boat, who is responsible for recording data and ensuring that all suitable habitat is surveyed.

3.4.4 Metrics, analysis, and reporting

3.4.4.1 Wadeable streams

The primary metrics used to monitor annual relative abundance of Pacific lamprey spawning in index reaches of Lawrence and Bull creeks will be (1) the total number of redds/reach and (2) the total number of redds/km of channel surveyed (both being the sum of redds counted from each monthly survey). Secondary metrics to summarize and report include live adults and carcasses observed per kilometer. Finally, stream discharge and water temperature data should be summarized to help understand the roles of these variables on spawning timing and survey errors (e.g., Figure 2-17). USGS gage data from Bull Creek can generally be used as a proxy for conditions in Lawrence Creek due to the proximity of the streams to each other.

3.4.4.2 Unwadeable streams

The primary metrics used to monitor annual relative abundance of spawning in unwadeable streams will be: (1) the total number of redds/site, (2) total number of redds/stream (summing all sites), and (3) the total number of redds/km of channel surveyed by site and stream. Secondary metrics to summarize and report include counts of live adults and carcasses for each site and stream. As with wadeable streams, stream discharge data (from USGS gages) and water temperature data (if available) for each river should be summarized. Importantly, redd densities (redds/km) from peak counts at index sites of unwadeable streams will not directly be comparable with redd densities from monthly surveys of index reaches in wadeable streams due to the different survey frequencies.

Trends in redd abundance over time for each index site (or index reach) and study stream can initially be evaluated visually using scatter plots of redds versus time. Trends can be then analyzed for statistical significance with linear regression models or other trend analyses. As with ammocoete trend analysis, selecting exact statistical methods and necessary data transformations will require careful assessment of data sets and evaluation of key statistical assumptions.

3.5 Migratory Adult Relative Abundance and Timing

Monitoring adult Pacific lampreys migrating from the ocean into the Eel River is an important component of the Wiyot Tribe’s long-term monitoring program because it can provide a coarse index of relative abundance of the entire Eel River basin population—which ammocoete and spawning surveys confined to the lower Eel River basin study area do not necessarily provide. Additionally, annual data collected through creel surveys will improve understanding of the basic biology and life history of the species, improving our understanding of population dynamics and factors limiting abundance. As with pilot surveys, we recommend a two-pronged approach for collecting creel survey data: (1) regular on-site interviews with eelers conducted at the Eel River mouth and (2) phone interviews with regular eelers thought to capture a high percentage of the lamprey harvested annually. Considerations for implementing each of these survey methods for long-term monitoring are presented below.

3.5.1 Site selection and spatial considerations

3.5.1.1 On-site creel surveys

On-site interviews will be conducted in the accustomed eeling location on the northern edge of the Eel River mouth. If WNRD staff learn that considerable eeling effort is occurring in other locations in the future, then creel surveys should be expanded to include these areas if feasible.

3.5.1.2 Phone interviews

All phone interviews will be conducted from the Wiyot Tribal office.

3.5.2 Timing and periodicity

3.5.2.1 On-site creel surveys

We recommend planning on-site creel surveys to cover the period from mid-January through May, when eeling has historically occurred at the mouth of the Eel River. However, as with 2014 pilot surveys, in years when eeling effort for the year is known to have ceased (based on conversations with regular eelers), surveys may be halted earlier. During the survey period, a minimum of two creel surveys per week should be conducted when weather, river flow, tide, and wave conditions are suitable for eeling. Surveys should be conducted during the daytime and timed to coincide with outgoing tide through the low slack tide, when most effort is known to occur based on pilot surveys.

3.5.2.2 Phone interviews

Due to the apparent difficulties conducting periodic phone interviews with regular eelers during the pilot season, as well as potential challenges interpreting data resulting from multiple interviews, we recommend conducting a single phone interview with each eeler soon after all known eeling for the season has ceased—typically in May.

3.5.3 Survey protocols

3.5.3.1 On-site creel surveys

Long-term monitoring field protocols for on-site creel surveys will be the same as pilot surveys (Section 2.3.1.1), except that datasheets will be streamlined and simplified, and questions about what part of the tide cycle and time of day participants typically eel will be excluded.

3.5.3.2 Phone interviews

Protocols and questions for phone interviews will be the same as for pilot surveys (Section 2.3.2.2), except that they will only be conducted once at the end of the season as described above.

3.5.4 Metrics, analysis, and reporting

3.5.4.1 On-site surveys

The primary metric used to monitor relative abundance of migrating adult Pacific lampreys will be catch-per-unit-effort (CPUE), or the number of individuals captured per hour of eeling effort. CPUE should be graphed by date and summarized by month and year. The total annual effort, documented number of lampreys harvested, and number observed but not captured should also be reported and compared with previous years. Importantly, because staffing constraints will only allow relatively infrequent creels surveys, CPUE data from these surveys should be viewed as coarse indices of annual relative abundance, designed to detect relatively large changes in the population. Data from each month and year should be compared cautiously, discussing results in the context of monthly and annual differences in eeling effort and gaps or other irregularities in collection of creel data that could impact conclusions. Secondary metrics that should be summarized and reported each year include sex ratio, length, weight, and sexual maturity level based on interdorsal length.

3.5.4.2 Phone interviews

Like on-site surveys, CPUE will be the primary metric derived from phone interview data for assessing annual relative abundance. Results of phone interviews should be viewed as an alternative annual index of relative abundance that can be used to better understand and help substantiate annual results of on-site creel surveys. Total reported harvest should also be summarized. Finally, answers to each phone interview question should be summarized and reported annually.

3.5.5 Opportunistic capture of migratory adults

In addition to implementing regular creel surveys during the core winter and spring migration and eeling periods specified above, we recommend attempting to capture adult Pacific lampreys that may be moving into the lower Eel River during other times of year in order to expand our overall understanding of run-timing and life-history diversity. Both historical (Petersen-Lewis 2009) and recent (D. Goodman, USFWS, pers. comm., 28 September 2015) accounts from the nearby lower Klamath River indicate the presence of migratory adult lampreys during the summer and early fall, and we hypothesize that such alternative migratory strategies may also exist in the Eel River. We therefore recommend exploratory summer and fall capture efforts, which may include both (1) attempting to capture adults moving into mouth of the Eel River with eel hooks and (2) passive approaches such as setting basket traps in the first riffles above tidewater. In addition to adding to our overall understanding of Pacific lamprey life history, these supplemental capture efforts will inform implementation and timing of potential expanded surveys as part of the adaptive monitoring process.

3.6 Data Management and Quality Control

An important element of long-term monitoring is developing efficient and effective procedures for data entry, management, and long-term storage. We therefore recommend development of an electronic database for efficient data entry and to facilitate secure storage of long-term monitoring data. The database should include data entry forms and linked tables for each element of data collected during ammocoete, spawning, and creel surveys. The database should be designed to ensure consistency, minimize data entry errors, and enable efficient quality control protocols.

In addition to developing a database, we recommend developing and implementing standard quality assurance/quality control protocols (QA/QC) for all data collection, entry, and report tables and figures. Specific steps to ensure accurate and repeatable data collection should include:

- Have an experienced staff member train and oversee new field staff during their initial data collection efforts.

- Use standardized datasheets to maintain clarity, efficiency, transparency and repeatability for field studies.
- Review datasheets at the close of each field visit to make sure all items are correctly annotated and accounted for.
- Develop database data entry forms that mirror field datasheets for ease of entry and to minimize entry errors.
- Scan and archive original datasheets upon return to the office.
- Double-check data entered into the electronic database using field datasheets.
- Develop comprehensive metadata to accompany all GIS work products.
- Archive original databases and only work with copies for any manipulation or analysis, to preserve the original condition.

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Appendices

Appendix A

List of Streams for Ammocoete Surveys

Stream Name	Tributary to	Drainage area (km²)	Stream size category	Lamprey previously documented (ET, LS, or UK)[1]	Pilot distribution, index, or spawning survey conducted (D, I, S)
Lower Eel Sub-basin					
Eel River	Pacific Ocean	9,430	Unwadeable	ET, LS, UK	I, S
Salt River	Eel River	104	Large		
Centerville Slough	Salt River	22	Medium		
Russ Cr	Centerville Slough	11	Small	UK	
Reas Cr	Salt River	5.1	Small	UK	
Francis Cr	Salt River	9.8	Small	LS	
Williams Cr	Salt River	16	Medium	UK	
Coffee Cr	Salt River	13	Small	UK	
Finch Cr	Eel River	1.9	Very small		
Palmer Cr	Eel River	5.5	Small	UK	
Little Palmer Cr	Palmer Cr	1.2	Very small		
Strongs Cr	Eel River	44	Medium	LS, UK	D
Barber Cr	Eel River	4.9	Very small		
Rohner Cr	Strongs Cr	12	Small	LS, UK	D
Jameson Cr	Strongs Cr	4.4	Very small		
North Fork Strongs Cr	Strongs Cr	7.9	Small		
Price Cr	Eel River	34	Medium	ET, LS, UK	D
Sweet Cr	Price Cr	5.2	Small		
Oil Cr	Eel River	4.7	Very small	UK	
Howe Cr	Eel River	28	Medium	LS, UK	D
Atwell Cr	Howe Cr	11	Small	LS, UK	D
Slater Cr	Eel River	6.0	Small		
Nanning Cr	Eel River	10	Small		
Dean Cr	Eel River	3.6	Very small		
Monument Cr	Eel River	14	Small		
Kiler Cr	Eel River	4.5	Very small		
Dinner Cr	Eel River	3.6	Very small		
Twin Cr	Eel River	5.4	Small		
Stitz Cr	Eel River	10	Small		
Jordan Cr	Eel River	12	Small		
Greenlow Cr	Eel River	5.0	Small		
Darnell Cr	Eel River	2.0	Very small		
Shively Cr	Eel River	9.8	Small		
Bear Cr	Eel River	22	Medium		D
Chadd Cr	Eel River	13	Small	LS	
Bridge Cr	Eel River	5.7	Small		
Larabee Cr	Eel River	231	Large	ET	
Chris Cr	Larabee Cr	3.5	Very small		
Carson Cr	Larabee Cr	5.7	Small		
Smith Cr	Larabee Cr	7.5	Small		
Burr Cr	Larabee Cr	22	Medium		
Mill Cr	Larabee Cr	11	Small		
Martin Cr	Larabee Cr	8.2	Small		
Thurman Cr	Larabee Cr	14	Small		

Stream Name	Tributary to	Drainage area (km²)	Stream size category	Lamprey previously documented (ET, LS, or UK)[1]	Pilot distribution, index, or spawning survey conducted (D, I, S)
Barn Cr	Thurman Cr	6.3	Small		
Boulder Flat Cr	Larabee Cr	10	Small		
Hayfield Cr	Larabee Cr	4.6	Very small		
McMahon Cr	Larabee Cr	8.9	Small		
Cooper Cr	Larabee Cr	9.1	Small		
Mountain Cr	Larabee Cr	4.0	Very small		
Allen Cr	Eel River	2.4	Very small		
Weber Cr	Eel River	4.7	Very small		
Van Duzen Sub-basin					
Van Duzen River	Eel River	1,109	Unwadeable	ET, LS, UK	I, S
Wolverton Gulch	Van Duzen River	15	Medium	UK	
Yager Cr	Van Duzen River	353	Large	ET, LS	S
Wilson Cr	Yager Cr	4.5	Very small		
Cooper Mill Cr	Yager Cr	10	Small		
Blanton Cr	Yager Cr	8.2	Small		D
Lawrence Cr	Yager Cr	107	Large	ET	S D??
South Fork Yager	Yager Cr	28	Medium	ET	D
Corner Cr	Lawrence Cr	5.1	Small		
Shaw Cr	Lawrence Cr	14	Small	ET, UK	D
Fish Cr	Lawrence Cr	4.3	Very small		
Booths Run	Lawrence Cr	15	Medium	ET, UK	D
Bell Cr	Lawrence Cr	12	Small		D
Strawberry Cr	Yager Cr	4.7	Very small		
North Fork Yager Cr	Yager Cr	121	Large		
Middle Fork Yager Cr	Yager Cr	121	Large		
Humphrey Cr	Middle Fork Yager Cr	6.8	Small		
Grouse Cr	North Fork Yager Cr	14	Small		
Lone Star Cr	Grouse Cr	6.5	Small		
Dairy Cr	North Fork Yager Cr	18	Medium		
Ellison Cr	North Fork Yager Cr	8.4	Small		
Freese Cr	North Fork Yager Cr	9.4	Small		
Indian Cr	North Fork Yager Cr	27	Medium		
Olsen Cr	Indian Cr	19	Medium		
Cuddeback Cr	Van Duzen River	4.1	Very small		
Fiedler Cr	Van Duzen River	2.9	Very small		
Cummings Cr	Van Duzen River	13	Small		
Fox Cr	Van Duzen River	3.1	Very small		
Hely Cr	Van Duzen River	9.5	Small		
Blue Slide Cr	Van Duzen River	2.3	Very small		
Root Cr	Van Duzen River	17	Medium	UK	
Grizzly Cr	Van Duzen River	49	Medium	ET, UK	D
Stevens Cr	Grizzly Cr	14	Small		

Stream Name	Tributary to	Drainage area (km^2)	Stream size category	Lamprey previously documented (ET, LS, or UK)[1]	Pilot distribution, index, or spawning survey conducted (D, I, S)
South Fork Eel Sub-basin					
South Fork Eel River	Eel River	1,767	Unwadeable	ET, LS	I, S
Bull Cr	South Fork Eel River	106	Large	ET, UK	S
Cow Cr	Bull Cr	6.1	Small		
Harper Cr	Bull Cr	3.9	Very small		
Squaw Cr	Bull Cr	12	Small		
Albee Cr	Bull Cr	3.6	Very small		
Mill Cr	Bull Cr	7.1	Small		
Cuneo Cr	Bull Cr	11	Small		D
North Fork Cuneo Cr	Cuneo Cr	3.1	Very small		
South Fork Cuneo Cr	Cuneo Cr	7.2	Small		
Burns Cr	Bull Cr	4.4	Very small		
Panther Cr	Bull Cr	8.3	Small		

[1] ET = *Entosphenus* or Pacific lamprey, LS = *Lampetra* species, UK = unknown species

Appendix B

Results of Statistical Analyses Informing Ammocoete Sampling at Index Sites

Table B-1. Pairwise correlation coefficients (r) between ammocoete density and covariates at Eel River index sites. Refer to Table 2-3 for descriptions of covariates. Analysis includes all ammocoetes >50mm of all species.

Covariate	*ammocoetes*	*dist.us*	*dist.bank*	*water.depth*	*substrate.depth*	*vegLive*	*organicDead*	*algalMat*
ammocoetes	1	0.02	0.67	0.09	-0.18	-0.37	-0.26	0.17
dist.us	0.02	1	-0.31	-0.05	-0.25	0.43	-0.07	-0.33
dist.bank	0.67	-0.31	1	0.03	-0.19	-0.74	-0.20	0.42
water.depth	0.09	-0.05	0.03	1	-0.20	0.33	-0.13	0.02
substrate.depth	-0.18	-0.25	-0.19	-0.20	1	0.03	0.03	-0.03
vegLive	-0.37	0.43	-0.74	0.33	0.03	1	0.25	-0.42
organicDead	-0.26	-0.07	-0.20	-0.13	0.03	0.25	1	0.04
algalMat	0.17	-0.33	0.42	0.02	-0.03	-0.42	0.04	1

Table B-2. Pairwise correlation coefficients (r) between ammocoete density and covariates at Van Duzen River index sites. Refer to Table 2-3 for descriptions of covariates. Analysis includes all ammocoetes >50 mm of all species.

Covariate	*ammocoetes*	*dist.us*	*dist.bank*	*water.depth*	*substrate.depth*	*vegLive*	*organicDead*	*algalMat*
ammocoetes	1	-0.12	0.18	0.02	-0.11	-0.08	0.05	0.00
dist.us	-0.12	1	-0.09	-0.34	0.37	0.41	0.06	-0.04
dist.bank	0.18	-0.09	1	0.01	-0.20	-0.15	-0.17	0.12
water.depth	0.02	-0.34	0.01	1	-0.14	-0.26	-0.05	0.05
substrate.depth	-0.11	0.37	-0.20	-0.14	1	0.13	0.12	0.12
vegLive	-0.08	0.41	-0.15	-0.26	0.13	1	0.39	-0.19
organicDead	0.05	0.06	-0.17	-0.05	0.12	0.39	1	-0.08
algalMat	0.00	-0.04	0.12	0.05	0.12	-0.19	-0.08	1

Table B-3. Results of the full ANOVA model evaluating relationships between ammocoete density and covariates for the Eel River.

Covariate	Df	Sum Sq	Mean Sq	F value	Pr(>F)[1]
site	1	3.832	3.832	6.955	0.011*
dist.bank	1	24.668	24.668	44.767	1.83E-07***
dist.us	1	0.870	0.870	1.579	0.215
substrate.depth	2	0.752	0.376	0.683	0.501
water.depth	1	1.310	1.310	2.377	0.130
vegLive	1	1.277	1.277	2.318	0.134
organicDead	1	1.489	1.489	2.702	0.107
algalMat	1	0.286	0.286	0.519	0.475
Residuals	50	27.551	0.551		

[1] Asterisks denote statistic significant at the following levels: *** = 0–0.001; ** = 0.001–0.01; * = 0.01–0.05

Table B-4. Results of the full ANOVA model evaluating relationships between ammocoete density and covariates for the Van Duzen River.

Covariate	Df	Sum Sq	Mean Sq	F value	Pr(>F)[1]
site	1	2.427	2.427	6.262	0.016*
dist.bank	1	0.434	0.434	1.120	0.295
dist.us	1	2.255	2.255	5.819	0.020*
substrate.depth	2	0.731	0.366	0.943	0.396
water.depth	1	0.384	0.385	0.992	0.324
vegLive	1	0.067	0.067	0.174	0.679
organicDead	1	0.094	0.094	0.244	0.624
algalMat	1	0.037	0.037	0.095	0.759
Residuals	50	19.381	0.388		

[1] Asterisks denote statistic significant at the following levels: *** = 0–0.001; ** = 0.001– 0.01; * = 0.01–0.05

Table B-5. P-values for multiple linear regressions of the form *sqrt(ammocoetes) ~site+covariate* for Eel River index sites. Analysis includes ammocoetes of all species ≥50mm.

Covariate[1]	P-value			R^2
	Regression	Site	Covariate	
dist.bank	2.44E-08***	0.095	2.37E-08***	0.459
dist.us	0.133	0.049*	0.527	0.068
water.depth	0.003**	0.002**	0.004**	0.187
vegLive	0.061	0.805	0.163	0.094
organicDead	0.026*	0.112	0.057	0.120
algalMat	0.155	0.108	0.768	0.063

[1] Significance levels: *** = 0–0.001; ** = 0.001–0.01; * = 0.01–0.05

[2] Substrate depth was not included in analysis since it was a categorical variable with three categories. Other analyses did not indicate a meaningful relationship between substrate depth and ammocoete density.

Table B-6. P-values for multiple linear regressions of the form *sqrt(ammocoetes) ~site+covariate* for Van Duzen River index sites. Analysis includes ammocoetes of all species ≥50mm.

Covariate[1]	P-value			R^2
	Regression	Site	Covariate	
dist.bank	0.035*	0.025*	0.304	0.111
dist.us	0.002**	0.001***	0.011*	0.193
water.depth	0.018*	0.006**	0.123	0.131
vegLive	0.018*	0.007**	0.123	0.131
organicDead	0.060	0.018*	0.954	0.094
algalMat	0.058	0.018*	0.818	0.095

[1] Significance levels: *** = 0–0.001; ** = 0.001–0.01; * = 0.01–0.05

[2] Substrate depth was not included in analysis since it was a categorical variable with three categories. Other analyses did not indicate a meaningful relationship between substrate depth and ammocoete density.

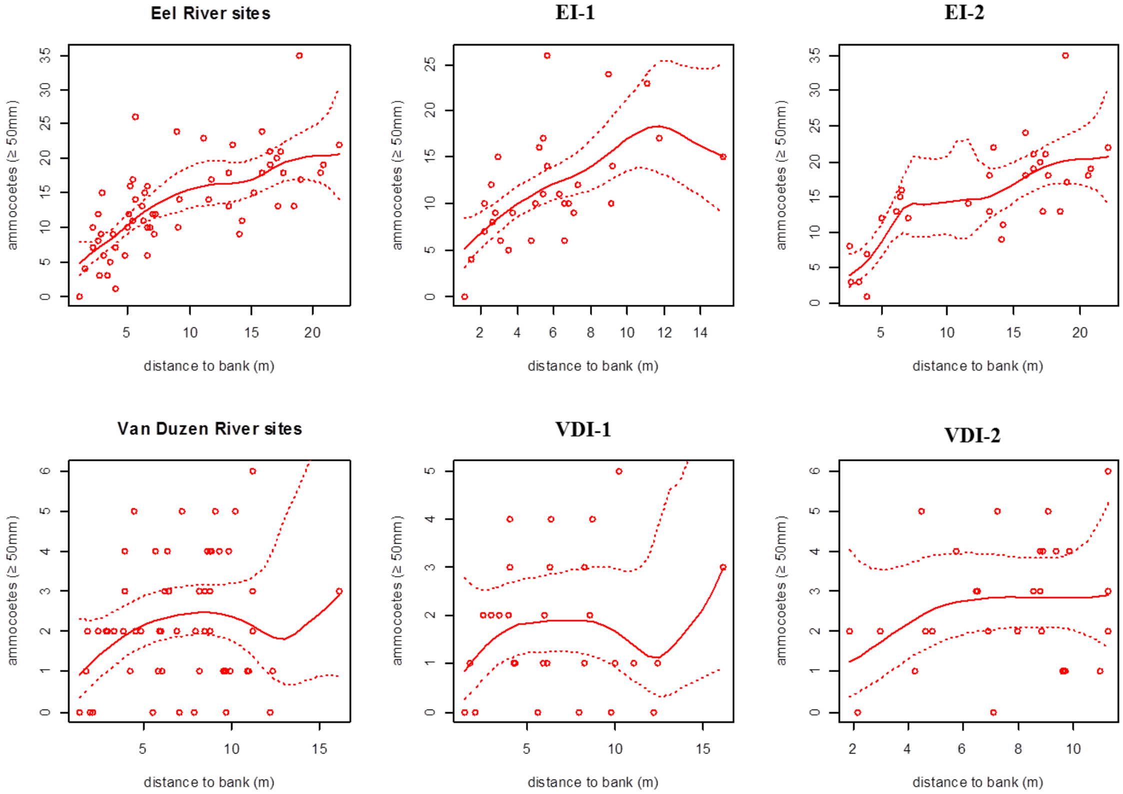

Figure B-1. Non-parametric model of ammocoete density as a function of distance to bank. The solid line is the function estimate and the dashed lines represent an approximate 95% variability band. Analysis includes all ammocoetes >50mm.

Appendix C

Pacific Lamprey Long-term Monitoring Program Summary Table

Table C-1. Summary of site selection and spatial considerations, timing and periodicity, required effort, and monitoring metrics for each element of the Pacific lamprey monitoring program.

Monitoring goal	Survey type	Spatial considerations			Sample periodicity		Seasonal timing	Effort required		Monitoring metrics	
		Sampling scale	Number of sites or reaches	Site selection	Long-Term	Within year		Crew members	Field days per year[1]	Primary	Secondary
Ammocoete distribution	Distribution surveys of wadeable streams	100–1,000 m reach	Approximately 70–80 streams [2]	Sample all accessible streams listed in Appendix A (excluding non-wadeable), prioritizing surveys by contributing drainage area	Once every 5 years	Once	July–October	2 or 3	15–20[3]	• Species presence / absence within "very small, small, or medium" streams • Upper distribution within "large" streams	• Ammocoetes / 100 m of channel surveyed • Length frequency • Suitable habitat area • Other relevant habitat characteristics
Ammocoete relative abundance	Index reaches in wadeable streams	100–300 m reach	10 reaches	Index reaches containing considerable Type I habitat in small and medium-sized, wadeable, and easily accessible streams	Annually	Once	July–October	2 or 3	5[4]	• Ammocoetes / 100 m [5]	• Suitable habitat area • Length frequency • Species composition • Temperature, flow, LWD
	Index sites in large and unwadeable streams	30–300 m^2 habitat patch	21 sites	Three spatially stratified sites within the mainstem Eel, Van Duzen, and South Fork Eel rivers and Yager, Lawrence, Bull, and Larabee creeks.	Annually	Once	July–October	4	9[6]	• Ammocoetes / m^2 [5]	• Range of and mean densities by site • Mean length and length frequency by site and stream • Species composition
Spawning relative abundance	Wadeable streams (monthly redd counts in index reaches)	2–3 km reach	4 index reaches	Bull Creek and Lawrence Creek (2 index reaches per stream)	Annually	Bi-weekly	April–June	2	12[7]	• Redds / reach • Redds/ km	• Live adults / reach • Carcasses / reach • Temperature and flow
	Unwadeable streams (peak redd counts at index sites)	Large, high-quality spawning habitat patch	21 sites	Spatially stratified within study area in Lower Eel (8 sites), Van Duzen (5 sites), and SF Eel rivers (8 sites)	Annually	Once soon after peak	Late May–mid-June	4 or 5	6[8]	• Redds / site • Redds / streams • Redds / km surveyed	• Live adults / site • Carcasses / site • Temperature and flow
Migratory adult relative abundance and harvest	On-site creel surveys	Single location	1	Mouth of Eel River (on-site surveys)	Annually	Twice per week	Mid-January through May	1 or 2	40[9]	• Catch-per-unit-effort	• Sex ratio • Length and weight • Sexual maturity level • Total documented harvest
	Phone interviews		1	Mouth of the Eel River (office-based surveys)	Annually	Once	Late spring or early summer	1	3	• Catch-per-unit-effort	• Total reported harvest

[1] Approximate; not including data management, analysis, and reporting.
[2] Assumes several streams in Appendix A will not be accessible and that 10 streams will not be sampled for distribution because they will otherwise be sampled annually for relative abundance.
[3] Assumes 1–2 surveys per day.
[4] Assumes 2 index reaches per day.
[5] Only includes ammocoetes that can be identified (>60 mm).
[6] Assumes 2 sites per day for unwadeable streams and 3 sites per day for large wadeable streams.
[7] Assumes 2 survey days per month per stream.
[8] Assumes 3–4 sites can be surveyed per day.
[9] Assuming at least 4 months of sampling and 2 surveys per week.