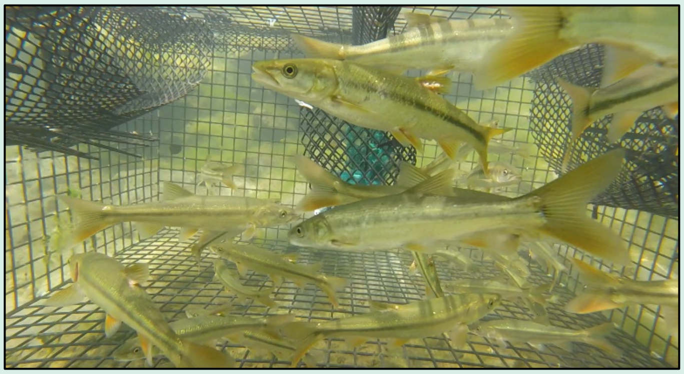
TECHNICAL MEMORANDUM ◦ SEPTEMBER 2020

Evaluation of Population Monitoring and Suppression Strategies for Invasive Sacramento Pikeminnow in the South Fork Eel River



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1 INTRODUCTION

1.1 Background, Need, and Objectives

Recent fisheries restoration and conservation efforts in the Eel River basin have largely focused on improving and protecting stream habitats, while less emphasis has been placed on understanding and mitigating adverse impacts of non-native aquatic species. Non-native predatory fish, in particular, can limit the productivity of already diminished native fish populations, limiting their ability to persist in degraded habitats and to recover in response to habitat restoration efforts. Of particular concern in the Eel River basin is the non-native Sacramento Pikeminnow, *Ptychocheilus grandis,* a large piscivorous cyprinid that was introduced into Lake Pillsbury in the upper mainstem Eel River around 1979 and has since expanded its distribution into much of the basin (SEC 1998, Brown 1990, Brown and Moyle 1997, Harvey et al. 2002, Kinziger et al. 2014).

Pikeminnow occur at very high densities in many parts of the watershed (e.g., White and Harvey 2001, Higgins 2020, PG&E 2020a) and therefore have potential to fundamentally alter the aquatic ecosystem and negatively impact native species. Various studies indicate that pikeminnow compete with, prey on, or alter behavior of juvenile salmonids, lampreys, and other native fishes in the Eel River basin (e.g., Brown and Moyle 1997, White and Harvey 2001, Reese and Harvey 2002, Nakamoto and Harvey 2003). Nakamoto and Harvey (2003) found that in the South Fork Eel River, the majority of the summer diet of pikeminnow larger than 250 mm (10 inches) was comprised of fish, with steelhead *Oncorhynchus mykiss*), Sacramento Sucker (*Catostomus occidentalis*), pikeminnow, and Northern Coastal Roach (*Hesperoleucus venustus navarroensis*), being the most common prey species, in descending order of frequency. They also reported larval lamprey as a frequent prey item and documented a 470-mm (18.5-in) Sacramento Pikeminnow that had consumed a 600-mm (24 in) adult Pacific Lamprey (*Entosphenus tridentatus*). Brown and Moyle (1997) reported salmonids, lampreys, and other native fish in the diet of pikeminnow as small as 100–150 mm (4–6 in). Presence of larger pikeminnow has also been shown to cause juvenile steelhead and Sacramento Sucker to increase use of higher velocity riffle habitats relative to other habits that may be more productive (Brown and Moyle 1991). A laboratory study by Reese and Harvey (2002) found that, at water temperatures of 20–23°C (68–74°F), growth of territorially-dominant juvenile steelhead was reduced by more than 50% in the presence of equal numbers of similarly-sized pikeminnow; however, no growth reduction was observed at 15–18°C (59–64°F).

There is some evidence that pikeminnow predation on juvenile salmonids may be somewhat lessened by water temperature-driven differences in summer distribution and by decreased predation during high, turbid, and cold winter and early-spring flows (Brown and Moyle 1981, Nakamoto and Harvey 2003). However, species that tolerate higher water temperatures such as Pacific Lamprey, Sacramento Sucker, and sculpins have a higher degree of overlap with pikeminnow during the summer and may be more vulnerable to predation (Brown and Moyle 1991, White and Harvey 2001, Stillwater Sciences 2014). White and Harvey (2001) found that introduced pikeminnow have had a large negative impact on the abundance of native sculpins in the Eel River, where their average density was less than 5% of that observed in the Smith and Mad rivers in the absence of pikeminnow. Additionally, Nakamoto and Harvey (2003) postulate that pikeminnow favor benthic prey such as such as larval lamprey, suckers, and sculpins during high and turbid winter flows.

The pressing need to further study, monitor, and address the impacts of Sacramento Pikeminnow on native fishes in the Eel River has been highlighted by various federal, state, and local entities. The Recovery Plan for the Southern Oregon/Northern California Coast Coho Salmon (*Oncorhynchus kisutch*) (NMFS 2014) indicates that predation and competition by pikeminnow are significant impediments to recovery of Eel River Coho Salmon populations and specifies the following recovery action: "*Determine the effectiveness of various pikeminnow suppression techniques and develop experimental control methods*." Likewise, the Coastal Multispecies Recovery Plan for California Coastal Chinook and Northern California Steelhead (NMFS 2016) lists "*reduce abundance of Sacramento Pikeminnow*" and "*assess feasibility and benefits of various methods to eradicate or suppress Sacramento Pikeminnow…*" as key recovery actions for Chinook Salmon (*Oncorhynchus tshawytscha*) and steelhead in the Eel River. The need to monitor the pikeminnow population and evaluate effectiveness of suppression approaches was also recently highlighted in the Eel River Action Plan (Eel River Forum 2016). Pikeminnow predation was also identified as a key threat to Eel River lampreys by USFWS (Goodman and Reid 2015). Finally, Stillwater Sciences (2014) identified Sacramento Pikeminnow predation as a potential factor limiting Pacific Lamprey population productivity in the Eel River and highlighted the need to better understand its impact and implement a pikeminnow control program to improve lamprey survival.

Despite the numerous studies demonstrating how introduced pikeminnow have disrupted the ecological balance of the Eel River and the issue being underscored in various plans, there have been only limited efforts in recent years to monitor their population, assess their impacts on native species, and develop and implement effective population control strategies. In 2005, Pacific Gas and Electric Company (PG&E) began implementing pikeminnow suppression and monitoring required by NMFS's Biological Opinion on the Potter Valley Hydroelectric Project (NMFS 2002). However, these efforts were halted in 2006 after gill nets aimed at suppressing pikeminnow resulted in high mortality of juvenile steelhead (PG&E 2007). These efforts were reinitiated in 2019 and 2020 (PG&E 2020a). Since 2005, PG&E has also used raft electrofishing to monitor pikeminnow abundance in index reaches of the upper Eel River between Van Arsdale Reservoir and Scott Dam (PG&E 2020a) and conducted annual backpack electrofishing and snorkel surveys aimed at monitoring juvenile steelhead and pikeminnow in index reaches between Cape Horn Dam and the Middle Fork Eel River (PG&E 2020b). The Eel River Recovery Project has also recently initiated efforts to monitor pikeminnow in the mainstem South Fork Eel River, implementing annual summer snorkel counts in the reach between Standish Hickey State Recreation Area (SRA) and Rattlesnake Creek from 2016 to 2020 (Higgins 2020).

This project was developed to help address the widely recognized need to systematically study and develop strategies for addressing the impacts of pikeminnow in the Eel River. Primary project objectives were:

- Develop and implement an approach to monitor pikeminnow abundance in the mainstem South Fork Eel River;
- Develop and evaluate effectiveness of approaches for suppressing the pikeminnow population;
- Improve understanding of pikeminnow diet and impacts on native fish species in the South Fork Eel River; and
- Generate initial recommendations to help guide future research, monitoring, and suppression efforts and support development of an adaptive management plan for Sacramento Pikeminnow in the Eel River basin.

Results from this project, along with ongoing work by other stakeholders, serve as an important starting point for developing and implementing a larger scale program to mitigate the impacts of Sacramento Pikeminnow on native fish in the Eel River. The Wiyot Tribe and Stillwater Sciences recently received additional funding to expand on the objectives of this project, implement more intensive removal of pikeminnow in the South Fork Eel River, and coordinate with stakeholders to develop an Eel River Sacramento Pikeminnow Management Plan. This work, referred to herein as Phase 2 of the project, is planned for 2020–2022.

1.2 Study Area

The Study Area for this project is the South Fork Eel River basin, located in Humboldt and Mendocino counties of northern California (Figure 1). The Study Reach includes 120 km (75.6 mi) of the mainstem South Fork Eel River, from Rattlesnake Creek to the confluence with the mainstem Eel River. Population monitoring was restricted to the 105-km (65-mi) reach downstream of Standish-Hickey State Recreation Area (SRA) to avoid overlap with annual pikeminnow census snorkel surveys conducted by the Eel River Recovery Project between there and Rattlesnake Creek (Higgins 2020). This 105-km reach is hereafter referred to as the "Monitoring Reach." As described in Section 2.2.1, the Monitoring Reach was divided into numbered sub-reaches, which constituted the sampling frame for snorkel surveys and were also used to describe the locations of suppression trials and other project activities.

The South Fork Eel River, which has a contributing drainage area of 1,785 km^2 (689 mi^2), is a major tributary to the Eel River, California's third largest river system (9,534 km^2 [3,681 mi^2]). The Wiyot Tribe has lived in the lower portions of the Eel River basin for millennia and has an interconnected relationship with the waters and fish of the Wiya't (Eel River). The Eel River has always been extremely important to the Tribe, as their ancestral territory encompasses its lower reaches.

Annual precipitation in the South Fork Eel River basin typically ranges from about 140 cm (55 in) in lower elevations to over 204 cm (80 in) at some higher elevation locations (PRISM Climate Group 2020). The rainfall pattern in the basin is characterized by wet winters and dry summers. During the period of record (1940–2020), discharge in the South Fork Eel River near Miranda (USGS gage 11476500) averaged 5,040 cfs for January and 53 cfs for September, with a peak flow of nearly 199,000 cfs in December 1964. The landscape in the watershed varies from redwood and Douglas-fir dominated forests in the coastal mountains to grassland and oak woodlands further inland. The geology of the basin is naturally unstable and the Eel River has a very high sediment load (Brown and Ritter 1971).

Recent land uses in the watershed include grazing, timber management, rural and residential development, gravel extraction, and widespread marijuana cultivation. These activities, along with historical widespread disturbance of the landscape from intensive logging and road building, followed by large floods in the 1955 and 1964, have caused extensive changes to much of the basin, including widespread landslides, channel aggregation, and loss of riparian vegetation that have contributed to habitat simplification in increased water temperatures (CDFW 2014). The South Fork Eel River is listed as an impaired water body due to excessive sediment and high summer water temperature (USEPA 1999).

Considerable effort has been made to restore degraded habitat in the South Fork Eel River basin. Recent, ongoing, and planned efforts have focused on restoring degraded instream habitats and managing water diversions to facilitate recovery of native fish populations, primarily Federally listed Chinook Salmon, Coho Salmon, and steelhead.

Figure 1. South Fork Eel River Study Area overview.

1.3 Sacramento Pikeminnow Species Overview

Understanding the basic biology, life history, and distribution of Sacramento Pikeminnow is critical for understanding its population dynamics, describing its impacts on native aquatic species, and developing effective population suppression strategies. This section provides an overview of the species, drawing largely from Wang (1986) and Moyle (2002), but also integrating more recent information.

The Sacramento Pikeminnow is a large minnow native to the Sacramento-San Joaquin River basin, the Pajaro, Salinas, Russian, Upper Pit rivers, and the Clear Lake Basin (Moyle 2002). In addition to the Eel River, the species has been introduced into Chorro and Los Osos creeks, which drain into Morro Bay in central California, and several reservoirs in southern California (Moyle 2002). In 2008, seven Sacramento Pikeminnow were detected in Martin Slough, a tributary to Elk River, which flows into Humboldt Bay; however, it does not appear that the species has become established in that watershed (Kinziger et al. 2014). The species is widely distributed in the South Fork Eel River, inhabiting much the mainstem and various tributaries (Harvey et al. 2002). In general, pikeminnow are restricted to lower gradient streams with summer water temperatures of 18–28°C (64–82°F) (Brown and Moyle 1997, Harvey et al. 2002, Moyle 2002).

Sacramento Pikeminnow reach sexual maturity after 3–4 years at a size of approximately 250 mm (10 in) standard length (SL), with males maturing one year earlier than females (Moyle 2002). The species can live to be at least 16 years of age and reach over 1,000 mm (39 in) standard length (SL) and (Scoppetone 1988, Moyle 2002). Typical fecundity is around 20,000 eggs, but large females can produce as many as 40,000 eggs (Wang 1986; Mulligan 1975, as cited in Moyle 2002). The species can spawn annually, but only spawns when conditions are favorable. Individuals in larger rivers or reservoirs are thought to move into tributaries to spawn, while fish in smaller streams may spawn locally (Taft and Murphy 1950, Mulligan 1975, Grant 1992; all as cited in Moyle 2002). Upstream movement associated with spawning has been documented to occur as early as March and as late as June (Wang 1986, Moyle 2002). Males are thought to gather in spawning areas prior to the arrival of females (Mulligan 1975, as cited in Moyle 2002). Spawning occurs when water temperatures exceed approximately 14°C (57°F) and is thought to take place at night (Wang 1986; Mulligan 1975, as cited in Moyle 2002). Spawning occurs in riffles or pool tail outs, where eggs released by females are fertilized by one or more males before sinking to the bottom and adhering to gravel and cobble substrate (Wang 1986, Moyle 2002). Eggs of Northern Pikeminnow (*Ptychocheilus oregonensis*), a closely related species, hatch in 4–7 days at 18°C (64°F) (Burns 1966, as cited in Moyle 2002). Newly hatched larvae, which are approximately 9 mm (0.35 in) long, remain in spawning gravels for a short time before dispersing to shallow backwater habitats or margins of pools (Moyle 2002). As they grow into the juvenile stage, pikeminnow typically inhabit shallower portions of pools and flatwater habitats often forming large mixed schools with Northern Coastal Roach (*Hesperoleucus venustus navarroensis*) (Moyle 2002, Gard 2005). Young-of-the-year pikeminnow can disperse widely, typically moving downstream (Moyle 2002).

During daytime, adult pikeminnow prefer pool and deeper run habitats with abundant cover such as boulder ledges, overhanging riparian branches, undercut banks, or large wood and are generally absent in riffles (Brown 1990, Moyle 2002, Gard 2005). Adults can be found in small schools, but the largest individuals are often solitary (Grant 1992, as cited in Moyle 2002). Adult pikeminnow are more active as dusk and dawn and may move into shallower water at night (Brown and Moyle 1981, Harvey and Nakamoto 1999). In the South Fork Eel River, Harvey and Nakamoto (1999) found that, during the summer, adult Sacramento Pikeminnow that held in large pools during the day commonly moved through adjacent riffles into shallower pools or runs at night, before returning to the large pools the next day. In October, they found that many fish occupied a pool body during the day and moved into either the pool head or pool tail at night.

Harvey and Nakamoto (1999) also documented adult pikeminnow tagged in the upper reaches of the South Fork Eel River making seasonal migrations, moving nearly 30 km (19 mi) downstream with increasing flows in the fall prior to moving back upstream in the spring, often returning to the same locations they inhabited the previous summer. Harvey and Nakamoto (1999) suggest that downstream movements in the fall are undertaken to escape harsh winter conditions and find low-velocity habitats, which are less abundant in the higher gradient, more confined upper reaches of the South Fork Eel River. Spring upstream migrations are presumably related to spawning but may also be related to feeding (Harvey and Nakamoto 1999).

Sacramento Pikeminnow are opportunistic and generalist predators, feeding on a variety of aquatic organisms and generally consuming prey in proportion to their availability (Brown 1990, Brown and Moyle 1997, Nakamoto and Harvey 2003). The diet of juvenile pikeminnow is dominated by aquatic insects, but they can prey on smaller fish when they are as small as 100 mm (4 in) in length (Brown and Moyle 1997, Harvey and Nakamoto 1999).The fraction of their diet composed of fish and crayfish increases with increasing size, in some cases making up over 75% of the diet of larger size classes (Brown and Moyle 1997, Nakamoto and Harvey 2003).
In the upper reaches of the South Fork Eel River, Nakamoto and Harvey (2003) found the summer diet of pikeminnow larger than 250 mm (10 inches) was dominated by fish, primarily juvenile steelhead, Sacramento Sucker, smaller pikeminnow, and Northern Coastal Roach. Larval Pacific Lamprey have also been shown to be a common prey item for pikeminnow in the Eel River, particularly during the wet season (Brown and Moyle 1997, Nakamoto and Harvey 2003).

Pikeminnow and other minnow species have a unique alarm response to predation that triggers fearful behavior and escape in conspecifics. A pheromone-like substance, known as s*chreckstoff* (German for fear or fright stuff) is released in response to mechanical trauma and injury—such as that inflicted by the teeth of predators (Stensmyr and Maderspacher 2012). The *schreckstoff* response has implications for efforts to remove pikeminnow, since it can limit capture with gear types that cause injury such as spearfishing and angling.

2 METHODS

2.1 Population Monitoring

The primary objective of population monitoring was to estimate abundance and describe distribution of Sacramento Pikeminnow in the Monitoring Reach (Figure 1), a critical step for assessing their impacts on native fish populations. Data from this task also helped identify pikeminnow population "hot-spots" to inform selection of locations for summer 2019 suppression trials. A secondary objective of the task was to improve understanding of summer distribution of juvenile salmonids, especially steelhead, to help avoid potential impacts to these species during suppression trials.

2.1.1 Sample sub-reach selection

The 105 km (65 mi) Monitoring Reach was divided into 58 sub-reaches that made up the sampling frame (Figure 2) from which a subset of sub-reaches was selected for conducting snorkel surveys. The sampling frame consisted of sub-reaches varying in length from 0.8 to 3.6 km (0.5 to 2.4 mi). Sub-reach start and end points were selected by the CDFW Coastal Monitoring Program (CMP) for salmonid redd surveys in the Eel River Basin and typically occur at tributary mouths or access points. To effectively sample this large stretch of river, we employed a spatially balanced sampling approach known as Generalized Random Tessellation Stratified (GRTS) to select 12 sub-reaches (Figure 2). These sub-reaches, totaling approximately 22 km (13.7 mi), were selected using the R-package "SDraw" (R Core Team 2019, McDonald and McDonald 2020). The GRTS site selection approach provides a major advantage over both simple random sampling and systematic sampling: the sample is guaranteed to be spatially balanced (McDonald 2003). For instance, a simple random sample may result in clustering of the sampled sub-reaches because no spatial data is used to inform the sample draw. Systematic sampling, on the other hand, may provide better spatial coverage than simple random sampling, but in the case of unusable sample sub-reaches (e.g. landowner denied access, crew safety, or difficult access) it is difficult to maintain spatial balance (Adams et al. 2011).

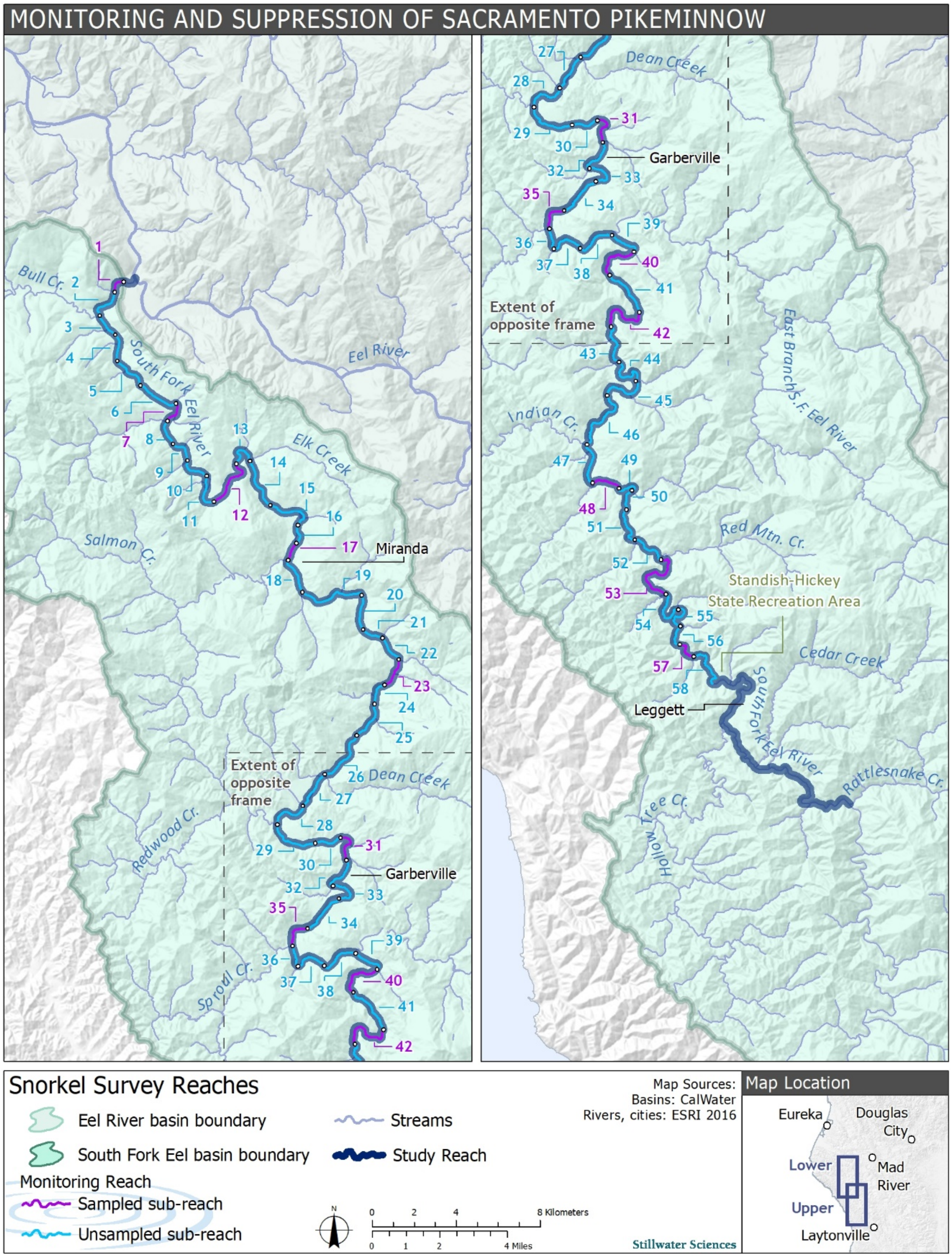

Figure 2. Monitoring Reach and sub-reaches sampled in the South Fork Eel River in summer 2018.

2.1.2 Snorkel surveys

Each of the 12 sub-reaches selected in the GRTS draw were sampled using single-pass, daytime snorkel surveys conducted between July 5 and August 1, 2018. All diveable portions of selected sub-reaches were sampled in their entirety, starting downstream and working upstream. Some riffles or portions of riffles were not sampled since they were too shallow or fast for effective surveying and expected to support few if any pikeminnow. However, where possible, diveable sections of riffles were surveyed to confirm the assumption of limited pikeminnow presence and help describe the summer distribution of juvenile steelhead in the Monitoring Reach.

Within each sub-reach, snorkel data were collected at the mesohabitat unit scale (pool, flatwater, riffle) to split surveys into manageable lengths and provide information on habitat preference. Each habitat unit was initially designated as a pool, riffle, or flatwater based on geomorphic characteristics of the channel. However, pool and flatwater unit types were lumped for analysis due to ambiguity in classifying many of them (e.g., short, deep sections with pool-like features in units that were otherwise characteristic of flatwater habitats or vice versa).

Lengths of sampled habitat units were calculated from GPS coordinates collected at the upstream and downstream ends of each unit. ArcGIS was used to examine summer 2018 satellite imagery and digitize the wetted channel between the downstream and upstream GPS points to calculate habitat unit length. Maximum depth of each habitat unit was recorded during snorkel surveys to help understand relationships between depth and pikeminnow presence and abundance. Shallower units were measured with a stadia rod and deeper units were measured with a handheld sonar device.

Each habitat unit was typically surveyed by divers moving upstream in adjacent dive lanes, counting fish as they escaped downstream. In habitat units (or parts of units) where it was not feasible to swim up the center of the channel due to high water velocity, divers typically swam or crawled up channel margins and counted all fish on their side of the channel. Divers communicated frequently to ensure all visible fish were counted and not double-counted. In locations where visibility was limited (e.g., deep pools and locations with submerged cover), divers dove towards the bottom to look for fish not visible from the surface.

Observed pikeminnow were assigned to the following size classes for subsequent summaries and analyses: 100–200 mm (4–8 in), 201–300 mm (8–12 in), 301–450 mm (12–18 in) and >450 mm (>18 in). Smaller (101–200 mm and 201–300 mm) and larger (301–450 mm and >450 mm) size classes were combined for certain analyses to present general differences between the groups. Pikeminnow smaller than 100 mm (4 in) were also counted, but those counts are considered coarse estimates due to their high numbers, potential for misidentification with the co-occurring Northern Coastal Roach, and the focus on accurately counting larger size classes. Additionally, these counts generally did not include large schools of small (<30 mm) larval / young-of-the-year pikeminnow present in the shallow channel margins. Non-target fish species were also counted and assigned to 100 mm (4 in) size classes. Divers paid particular attention to detecting juvenile salmonids to help describe their summer distribution and inform efforts to avoid them during 2019 electrofishing trials. Other relevant ecological observations such as lamprey redds were also noted. Finally, horizontal underwater visibility was visually estimated at the beginning of each sampled sub-reach.

2.1.3 Abundance estimates

Snorkel counts of pikeminnow from the 12 surveyed sub-reaches were used to obtain abundance estimates with 95% confidence intervals for each size class in the Monitoring Reach using a simple random sample approach implemented through the R package, "survey" (Lumley 2020, R Core Team 2019). Linear density (fish/km) of each size class was calculated by dividing the total number of pikeminnow estimated for the Monitoring Reach by the length of the Monitoring Reach.

2.2 Evaluation of Suppression Strategies

Evaluating potential methods for removing pikeminnow is an important part of developing and implementing a successful and cost-effective large-scale suppression program. The primary methods evaluated in this study were boat electrofishing (Section 2.2.1), netting and trapping (Section 2.2.2), and angling (Section 2.2.3). Evaluations of various other methods were planned but not conducted due to permitting restrictions and delays or logistical constraints. These methods and other potential pikeminnow population suppression strategies are discussed in Section 4.2.4.

2.2.1 Boat electrofishing

2.2.1.1 Site selection

Boat electrofishing trials were limited to portion of the Study Reach downstream of the East Branch of the South Fork Eel River (rkm 65) to avoid potential impacts to juvenile steelhead, which were determined through 2018 snorkel surveys to be extremely rare downstream of rkm 70. Within this portion of the Study Reach, 13 sites with potential to provide boat trailer access and pool and run habitats deeper than 1.5 m (5 ft) with habitat likely to support larger pikeminnow were initially identified using aerial imagery and information collected during 2018 snorkel surveys. Reconnaissance surveys confirmed that nine of these sites had suitable boat access and pikeminnow habitat, and these sites were selected for boat electrofishing (Figure 3). Boat electrofishing sites ranged in length from approximately 150 to 850 m (490 to 2,800 ft) and consisted of one or more pool or flatwater habitats navigable by jet boat. Sites were typically bounded by shallow riffles or flatwaters that were not navigable or were considered to be poor pikeminnow habitat.

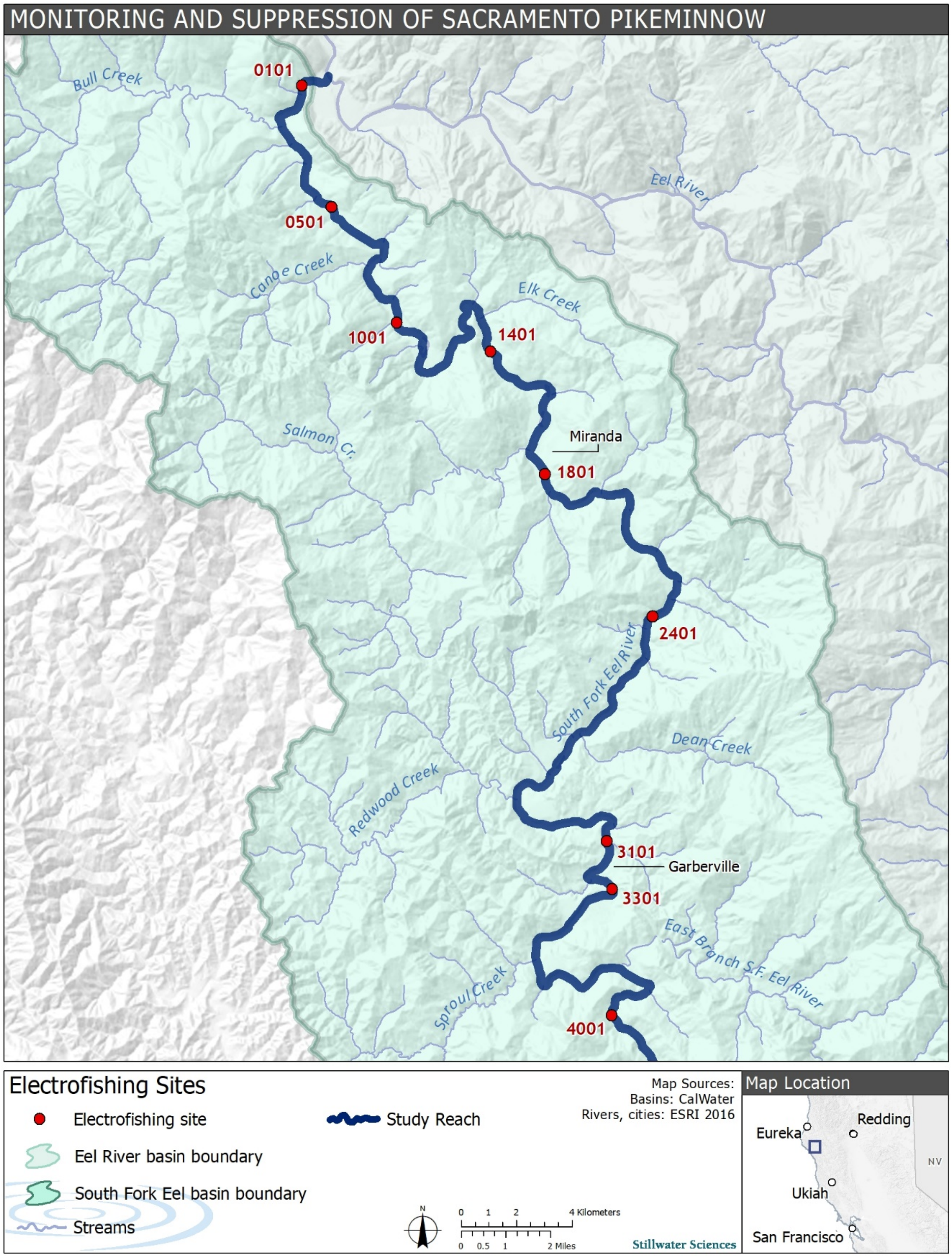

Figure 3. Boat electrofishing sampling sites in summer 2019.

2.2.1.2 Pilot efforts

The first two days of boat electrofishing were considered pilot efforts and used to set up and troubleshoot the boat electrofishing system and refine various field methods. The electrofishing boat consisted of a 16-ft G3 Jon boat outfitted with a Smith-Root model 7.5 GPP electrofisher powered by a gas generator (Figure 4). During the pilot efforts, the electrofishing boat was initially equipped with a traditional boom-mounted anode system consisting of two anodes hanging into the water from 2.4-m (8-ft) booms emanating from the bow of the boat (Figure 4). A throw anode—consisting of a 1.2-m (4-ft) fiberglass handle connected to the electrofishing unit by a long cord on one end and two metal rings and a lead weight affixed to the other end to facilitate sinking—was also tested (Figure 5). The throw anode was utilized for the remainder of the trials due to apparent improvement in capture efficiency during pilot days. The throw anode provided increased effective range [6–9 m (20–30 ft)] from the boat compared to the booms [1.5–3 m (5–10 ft)] and allowed greater maneuverability since the booms were removed from the bow. Pros and cons of different anode styles are discussed in more detail in Section 4.

During the pilot efforts, the electrofisher was initially set to relatively low voltage and duration of shocking was minimized to reduce potential impacts to non-target species. However, Sacramento Pikeminnow were resistant to lower voltages and evaded capture. For this reason, and since salmonids were not observed during snorkeling or captured during electrofishing, voltage was steadily increased until pikeminnow could be effectively captured. Ultimately, full power settings of 1,000 volts DC current at 100% of the range (voltage is fine-tuned by percent of range dial) and a frequency of 60 pluses per second were required to sufficiently stun pikeminnow for capture with the throw anode set-up. Very few pikeminnow were burned or otherwise injured and very few non-target species were encountered.

Another technique that was tested during pilot efforts was deploying multiple, connected fyke nets across a pool tailout at the downstream end of a site, then electrofishing from upstream to downstream. The goal was to push pikeminnow fleeing the electrical field downstream into the net. However, after only capturing a few pikeminnow <100 mm, this method was abandoned due to the low yield and considerable amount of time required for net deployment.

Figure 4. Jon boat equipped with a traditional anode set-up.

Figure 5. Jon boat equipped with a throw anode set-up (top) and throw anode being deployed (bottom).

2.2.1.3 Electrofishing trials

Upon arrival at each site, signs warning the public to stay away from the water were posted in a visible location and any individuals present were advised to stay away from the water in the vicinity of the electrofishing boat. Time of arrival and departure at the site and time at which electrofishing trials were initiated and stopped were recorded to allow calculations of catch-per-unit-effort (CPUE). The downstream and upstream boundaries of the sample site were identified, and GPS coordinates were recorded. Snorkel surveys were performed at each site before initiating boat electrofishing trials, either immediately before electrofishing or during reconnaissance surveys conducted less than 10 days earlier. The primary purpose of these snorkel surveys was to ensure no juvenile salmonids or schools of Sacramento Sucker were present. Additionally, observations on the locations of pikeminnow schools were used to target these habitats during electrofishing. As described below, snorkel counts were also compared to electrofishing capture data from the same site to help understand effectiveness of the technique at removing fish.

Boat electrofishing field crews consisted of five people: three individuals working in the boat and two fish processers on shore. Electrofishing with the throw anode involved one person operating the anode and a foot-operated electroshocking switch, one person netting with an 3.5-m (11-ft) long-handled dip-net, and a boat operator who also controlled an emergency shutoff switch. All crew members wore rubber electrical insulating gloves for safety. Both the anode operator and the netter stood on the bow scanning for pikeminnow to target with the anode (Figure 5). When one or more pikeminnow was seen, voltage was applied and the anode was thrown at the fish. Stunned fish were then captured with the long-handled dip net and transferred to an onboard cooler. When high quality habitat was present but no pikeminnow were seen or wind made visibility difficult, “blind” anode throws were made with occasional effectiveness. In some situations where fish were holding in deeper water or hiding in a known location, the operator would let the anode sink closer to the fish before applying voltage. Pushing the fish upstream towards a riffle or towards shallower water was also a strategy used to target pikeminnow with the throw anode. Length of the dip nets limited the maximum depth that was effectively electrofished to approximately 3 m (10 ft), and since many pikeminnow tended to sink when stunned, quick capture was often critical to ensure pikeminnow did not sink out of range.

Electrofishing was generally performed in the downstream to upstream direction for ease of boat maneuverability and netting. Multiple electrofishing passes were typically made at a site, moving the boat systematically from downstream to upstream within in a habitat unit or pool/flatwater sequence and targeting visible fish or likely habitat until capture rates declined substantially. Three or four passes were generally the maximum performed before most fish were assumed to be either captured or hiding in deep water, interstices in the stream bed, or algal mats. Only pikeminnow >100 mm were targeted since smaller individuals would often slip through the net mesh and were too plentiful to devote extensive effort capturing.

All captured pikeminnow were placed in a concentrated MS-222 kill bath in the boat for subsequent processing. Native species were immediately transferred to a water-filled and aerated cooler on shore and returned to the capture location following electrofishing. Tissue samples and length data were collected from Sacramento Suckers for a population genetics study by USDA Forest Service Redwood Sciences Laboratory.

All pikeminnow >100 mm were measured to the nearest mm standard length (Figure 6) and weighed to the nearest tenth of a gram. The few individuals <100 mm captured were tallied. Gut samples for diet evaluation were collected from a target of 30 pikeminnow from each size class:

100–200 mm, 201–300 mm, 301–450 mm, and >450 mm. Following methods in Nakamoto and Harvey (2003), the entire digestive tract of fish larger than 150 mm (6 in) was removed down to the second bend in the S-shaped intestine and preserved in 90% ethanol. Individuals <150 mm were preserved whole and the body cavity was punctured to improve preservation.

Muscle tissue was also collected from individuals sampled for gut contents for future isotopic diet analysis, which is outside the scope of the current study. Tissue was removed from below the dorsal fin near the lateral line and immediately placed on ice before being stored in a freezer for subsequent processing and analysis with a mass spectrometer in a stable isotope lab (to be completed during Phase 2 of this project). Scale samples were also collected from behind the dorsal fin above the lateral line for future age and growth analyses. Finally, caudal fin tissue was collected from 20 males and 20 females identified from examination of gonads, stored in ethanol, and provided to the Idaho Department of Fish and Game Eagle Fish Genetics Lab to support their efforts to develop a genetic sex marker for Northern Pikeminnow.

Figure 6. Comparison of standard and total length as measured on Sacramento Pikeminnow.

2.2.1.4 Data analysis

For capture and catch-per-unit effort (CPUE) summaries, pikeminnow were grouped into the same size classes used for snorkel counts (Section 2.1). Pikeminnow length frequency was presented in a histogram using 10-mm length bins.

Two CPUE metrics were calculated for each site to describe the overall effort required to remove pikeminnow with boat electrofishing:

1. Fish captured per hour spent electrofishing, starting when the boat was in the water until it came to shore immediately after electrofishing ceased. This metric included time spent positioning the boat, netting fish, shuttling captured fish to processors on shore, and, in some cases short lunch breaks.
2. Fish captured per hour spent at a site, from time of arrival until departure. In addition to time spent electrofishing, this metric included setting-up and organizing equipment, snorkeling at some sites, launching and trailering the boat, and processing fish that remained after electrofishing ceased. Depending on the site and number of fish captured, typically a total of 1–2 hours was spent at each site launching the boat, setting up, processing fish, and packing up before and after electrofishing.

The number of seconds of voltage applied during electrofishing was also recorded with a built-in timer on the electrofisher, but this effort was not reported since it was not considered to adequately describe overall effort.

For CPUE calculations, fish were grouped into 101–300 mm and >300 mm size classes. Pikeminnow captured during the two initial pilot days of electrofishing were omitted from CPUE calculations, since substantial time was devoted to setting up and troubleshooting equipment on those days and thus they were not representative of typical CPUE.

2.2.2 Netting and trapping

Pilot-level trials of seine nets and baited box traps were conducted in the South Fork Eel River in summer 2019 to help understand their potential for sampling different types of habitats and pikeminnow size classes as part of a multipronged population suppression strategy. Permitting delays related to a federal government shutdown limited these trials to the reach downstream of the East Branch of the South Fork Eel River.

2.2.2.1 Seining

Seine nets were tested at five sites in the South Fork Eel River between rkm 0 and rkm 58 (near Garberville) from August 13–21, 2019 to evaluate their effectiveness at sampling smaller size classes of pikeminnow (<300 mm) in a variety of habitat types and locations. Seining was conducted at the same general sites as baited box trap trials but was typically conducted in shallower [0.6–1.6 m (2–4 ft)] margins or flatwater habitats not directly adjacent to the deeper pools being sampled passively with box traps. Most seining was conducted with a 15-m (50-ft) long and 1.5-m (5-ft) deep knotless nylon seine with 0.5-cm (0.19-in) mesh, but a 6-m (20-ft) net was also briefly tested.

Three seine passes were conducted at each site using standard beach seining techniques, except that for most trials, the area to be sampled was baited with chicken liver to attract fish to the area for several minutes prior to seining. Captured fish were brought to shore for processing as described above for boat electrofishing.

2.2.2.2 Baited box traps

Baited box traps were tested in pool habitat at five sites in the South Fork Eel River between rkm 0 rkm 58 (near Garberville) from August 13–21, 2019, with the objective of testing their utility for capturing larger size classes of pikeminnow (>200 mm) in deep and complex habitat where electrofishing can be ineffective. The traps consisted of 1.2 m x 1.2 m x 0.6 m (4 ft x 4 ft x 2 ft) cubes constructed of plastic-coated wire with 3.8 cm (1.5 in) square mesh and two 33 cm x 18 cm (13 in x 7 in) openings with inward facing plastic "fingers" designed to allow relatively large fish to enter but not exit (Figure 7). Hard plastic or plastic mesh bait containers were affixed to the center of the trap. Salmon roe, anchovies, and chicken liver were evaluated as baits for their relative effectiveness at attracting pikeminnow. A GoPro waterproof camera was attached to the side of the trap during deployment to monitor pikeminnow behavior relative to the traps and aid in evaluation of their response to the different baits. The video footage was both recorded and viewed in real time on a tablet via a Bluetooth antenna.

Depending on the site, either one or two traps were deployed. Traps were typically deployed by 2–3 people by carrying and then swimming with them to the desired locations before positioning on the pool bottom. Buoys were attached to each top corner of the trap so it would float during positioning, but removed just prior to deployment. Traps were retrieved by one person diving to lift the trap off the bottom while another person on shore pulled the trap by an affixed rope. Traps were generally fished for 1–2 hours during daytime, except for a single test at night. After deploying the traps at the five sites and determining that numerous small pikeminnow (approximately 100–200 mm) entered the traps, but could escape through the large mesh openings, one of the traps was modified by wrapping it with 1.5-cm (0.6-in) square mesh netting and deployed again at the five sites on later dates to attempt to capture these smaller fish.

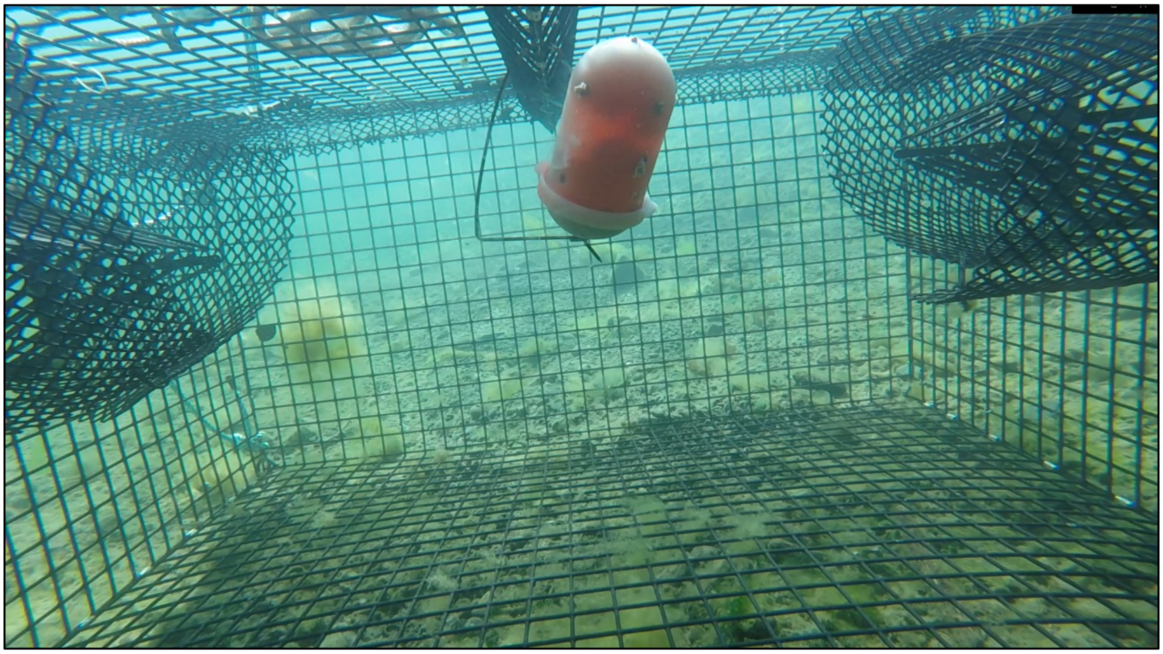

Figure 7. Baited frame trap during deployment.

2.2.3 Angling

Relatively limited effort was devoted to capturing pikeminnow by angling during the winters of 2017/18 and 2018/19 with the primary purpose of collecting winter diet samples and secondary purpose of evaluating the efficacy of the method for removing pikeminnow. A variety of barbless artificial baits (spoons, spinners, plugs) were tried, but the primary and most effective bait used was night crawlers fished with a typical steelhead drift fishing rig (barbless hook tied onto a leader with egg loop, a small float, and a lead weight). In addition, several pikeminnow captured by a steelhead fisherman were donated to the project and examined for diet. Diet samples were processed as described in Section 2.3.

2.3 Diet Evaluation

As described above, gut samples were collected from a subset of Sacramento Pikeminnow in each size class captured during summer 2019 boat electrofishing trials for direct (visual) examination of diet. Gut samples from the relatively small number of pikeminnow captured during winter angling (Section 2.2.3) in the lower South Fork Eel River were also examined.

Gut samples were sorted in the lab by WNRD staff. Samples from each fish were placed into a dissecting tray and identifiable prey items were sorted into the following categories: insects, crayfish, fish, and other. The number of individuals in each prey type category were enumerated and a combined wet weight of each type was recorded to the nearest 0.1 g. Fish in diet samples were examined and identified to the lowest taxon possible. Where possible, insects were identified to order and the most common taxa in each sample were noted.

Percentages of each prey type in the diet were calculated by summing the weight of each type from individual gut samples and calculating an overall percentage for each size class. Percentage of gut samples in which each prey type occurred, or frequency of occurrence, was also calculated and reported for non-empty samples in each size class.

2.4 Water Temperature

To support efforts by this and future studies to understand pikeminnow seasonal movement patterns and bioenergetics, four continuous water temperature loggers were deployed in the mainstem South Fork Eel River between summer 2018 and winter 2019. Loggers were set up to record temperature readings every 30 minutes. Daily and annual temperature statistics from the resulting data are summarized in Appendix A.

3 RESULTS

3.1 Population Monitoring

3.1.1 Survey effort and conditions

Twelve of the 58 sub-reaches in the South Fork Eel River Monitoring Reach were snorkeled between July 5 and August 1, 2018 (Figure 2 and Table 1). A total of 21.6 km (13.4 mi) of the 105-km (65 mi) reach (21%) comprising 96 mesohabitat units was surveyed. Within the 12 snorkeled sub-reaches, 54 habitat units making up approximately 70% of the sampled length were designated as pool or flatwater habitat. Forty-two units were designated as riffle habitat. Estimated underwater visibility during surveys ranged from 3 m (10 ft) to over 4.6 m (15 ft). Stream flow during the surveys ranged from 43 to 90 cfs at Miranda (USGS gage 11476500) and 22 to 46 at Leggett (USGS gage 11475800).

Table 1. Summary of sub-reaches snorkeled in the South Fork Eel River in summer 2018.

Sub-reach	Sampled date	River kilometer of downstream end	Length (km)	Number of units by habitat type		Length by habitat type (m)	
				Pool / flatwater	Riffle	Pool / flatwater	Riffle
1	7/5/2018	0.0	0.8	2	2	557	253
7	7/17/2018	9.4	1.2	2	1	1,027	182
12	7/11/2018	16.2	2.9	8	4	1,775	1,106
17	7/17/2018	26.3	1.2	2	1	911	293
23	7/18/2018	36.6	1.4	2	2	1,037	411
31	7/19/2018	51.4	1.6	3	3	1,227	365
35	7/19/2018	58.4	1.3	3	3	492	851
40	7/12/2018	66.0	2.0	5	4	1,363	656
42	7/20/2018	70.6	2.8	7	7	1,997	827
48	7/24/2018	85.6	1.5	5	3	999	483
53	7/25/2018	92.9	3.6	11	9	2,597	969
57	8/1/2018	101.2	1.2	4	3	1,059	116
Total			**21.6**	**54**	**42**	**15,042**	**6,512**

3.1.2 Sacramento Pikeminnow abundance and habitat use

Relatively large numbers of pikeminnow were counted in each of the 12 sub-reaches sampled (Table 2). Overall, and in most sub-reaches, number of pikeminnow counted decreased with increasing fish size.

Table 2. Number of Sacramento Pikeminnow counted in sampled sub-reaches of the South Fork Eel River by size class in summer 2018.

Sub-reach	0–100 mm[1]	101–200 mm	201–300 mm	301–450 mm	>450 mm
1	336	98	126	25	34
7	265	1	14	25	7
12	1,849	644	169	62	25
17	1,250	321	191	37	2
23	740	82	68	37	7
31	1,325	102	89	81	14
35	120	11	71	16	4
40	1,427	257	60	38	8
42	350	186	38	106	8
48	574	500	50	7	0
53	2,047	1,232	291	61	42
57	395	1,130	28	30	4
Total	**10,678**	**4,564**	**1,195**	**525**	**155**

[1] Considered a coarse estimate due to high numbers of small fish, potential misidentification as the co-occurring Northern Coastal Roach, and focus on surveying habitats preferred by larger size classes.

Estimates of abundance and linear density of pikeminnow in the Monitoring Reach based on counts in sampled sub-reaches are presented by size class in Table 3. Estimated abundance in the Monitoring Reach ranged from approximately 50,000 fish in the 0–100 mm size class to fewer than 800 fish in the >450 mm size class. Overall densities ranged from about 500 fish/km for the <100 mm size class to 7 fish/km for the >450 mm size class (Table 3).

Table 3. Estimated abundance and linear density of Sacramento Pikeminnow in the South Fork Eel River downstream of Standish-Hickey State Recreation Area in summer 2018.

Size class (mm)	Abundance		Linear density (fish/km)	
	Estimate	95% confidence interval	Estimate	95% confidence interval
0–100[1]	51,610	32,275–70,946	488	305–671
101–200	22,059	9,742–34,377	209	92–325
201–300	5,776	3,400–8,152	55	32–77
301–450	2,537	1,700–3,375	24	16–32
>450	749	355–1,143	7.1	3.4–10.8

[1] Considered a coarse estimate due to high numbers of small fish, potential misidentification as the co-occurring Northern Coastal Roach, and focus on surveying habitats preferred by larger size classes.

No clear longitudinal patterns in pikeminnow linear density were observed across the 12 sampled sub-reaches, apart a general increase in density of the 101–200 mm size class from downstream to upstream (Figure 8). Certain habitat units within sampled sub-reaches were identified as being hotspots for larger pikeminnow. For example, 34 pikeminnow >450 mm and 25 in the 301–450 mm size class were counted in a long, consistently deep [1.8–2.7 m (6–9 ft)] run with abundant cover just upstream of the South Fork Eel River confluence (Sub-reach 1). In a deep pool just upstream of Red Mountain Creek (Sub-reach 53), 34 pikeminnow >450 mm and 16 in the 301–450 mm size class were counted. Densities of the >450 mm size class were over 80 fish/km in both habitat units, considerably higher than overall densities in those sub-reaches.

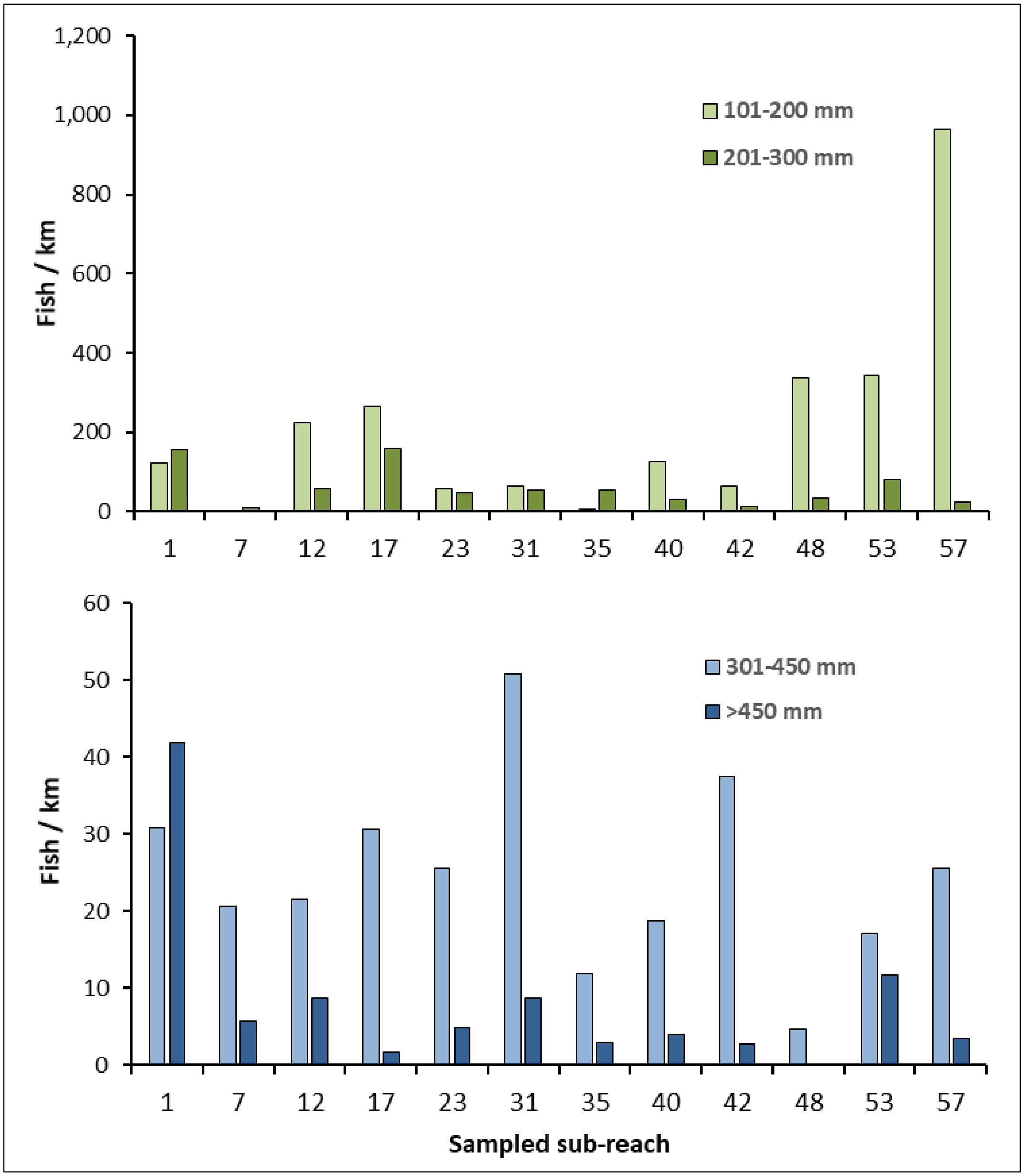

Figure 8. Observed densities of Sacramento Pikeminnow by sampled sub-reach and size class in the South Fork Eel River in summer 2018. Sub-reaches ordered from downstream to upstream (see Figure 2).

As expected, observed densities of pikeminnow were higher in pool and flatwater habitats and extremely low in riffles (Table 4). In fact, the only pikeminnow counted in habitat units classified as riffles were from short, slower, and deeper sections that were lumped with the longer riffle.

Table 4. Linear density (fish/km) of Sacramento Pikeminnow observed by size class and habitat type in sampled sub-reaches of the South Fork Eel River.

Size class (mm)	Sacramento Pikeminnow linear density (fish/km)		
	Pool/Flatwater	**Riffle**	**Total**
0–100[1]	682.0	64.5	495.4
101–200	298.1	12.3	211.7
201–300	79.4	0.0	55.4
301–450	34.6	0.6	24.4
>450	10.2	0.2	7.2

1 Considered a coarse estimate due to high numbers of small fish, potential misidentification as the co-occurring Northern Coastal Roach, and focus on surveying habitats preferred by larger size classes.

In general, very few pikeminnow in the larger size classes (301–450 mm and >450 mm) were observed in habitat units with maximum depth less than approximately 1.2 m (4 ft), while the highest numbers were observed in habitat units deeper than about 2.4 m (8 ft) (Figure 9). However, not all deep locations had high numbers of large pikeminnow, and some had none. Data on other habitat elements such as cover were not recorded, but pikeminnow generally preferred locations with abundant cover in the form of large wood, boulders, or thick overhanging vegetation. Smaller pikeminnow (101–300 mm) were generally most abundant in habitat units with maximum depths of 1.2–3.7 m (4–12 ft) (Figure 9).

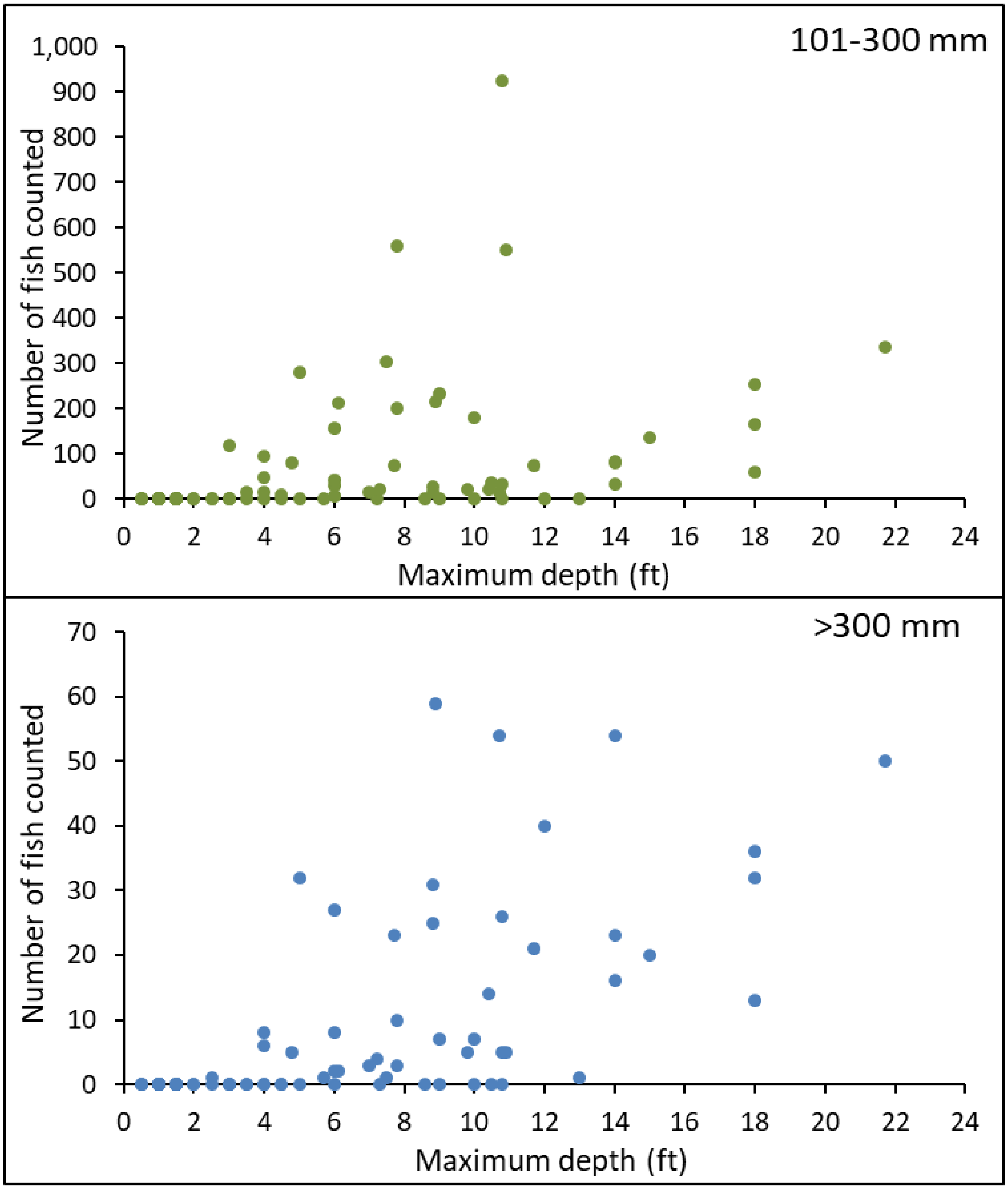

Figure 9. Observed numbers of Sacramento Pikeminnow versus maximum depth of sampled habitat unit. Smaller (101–200 mm and 201–300 mm; top) and larger (301–450 mm and >450 mm; bottom) size classes were combined to show general patterns.

3.1.3 Non-target species

Very few fish other than Sacramento Pikeminnow were observed during summer 2018 snorkel surveys. A total of 27 juvenile steelhead were observed. All steelhead were observed upstream of the East Branch South Fork Eel River (rkm 65.4), except for a single individual in Sub-reach 12 (rkm 16.2; near Myer's Flat). Sixteen of the juvenile steelhead were observed in Sub-reach 42 (rkm 70.6), just downstream of Richardson Grove State Park (Table 5). The only other fish species seen were five Sacramento Sucker, a single Threespine Stickleback (*Gasterosteus aculeatus*), and large numbers of Northern Coastal Roach that were not enumerated (Table 5). In addition, divers observed approximately 150 Pacific Lamprey redds, primarily in the sub-reaches downstream of Dean Creek (rkm 44).

Table 5. Numbers of non-target fish species counted in sampled sub-reaches of the South Fork Eel River by size class in summer 2018.[1]

Sub-reach	Juvenile steelhead				Sacramento Sucker	Threespine Stickleback
	>100 mm	101–200 mm	>200 mm	All sizes	301–400 mm	<50 mm
1	0	0	0	0	0	0
7	0	0	0	0	0	0
12	0	1	0	1	5	0
17	0	0	0	0	0	0
23	0	0	0	0	0	0
31	0	0	0	0	0	0
35	0	0	0	0	0	0
40	0	0	0	0	0	0
42	1	0	15	16	0	0
48	0	3	2	5	0	0
53	0	0	3	3	0	0
57	0	0	2	2	0	1
Total	**1**	**4**	**22**	**27**	**5**	**1**

1 Large numbers of Northern Coastal Roach that were observed but not counted.

3.2 Evaluation of Suppression Strategies

3.2.1 Boat electrofishing

Nine sites were sampled with boat electrofishing from July 10 to 19, 2019 (Figure 3, Table 6). Site length ranged from 140 to 858 m, with a total sampled length of 3,856 m. As described in Section 2.2.1.2, the first two days of sampling (sites 3101 and 3301) were considered pilot efforts. Site 3301 was revisited 7 days later since only small numbers of the smaller size classes were removed during the pilot effort. A traditional anode set-up was tested on the first two days of sampling, but after relatively low success in capturing large pikeminnow during these initial trials, a throw anode was used for the remainder of electrofishing. A channel-spanning fyke net was also deployed at the downstream end of Site 3301 to test its utility for capturing pikeminnow fleeing the electrical field, but it was not utilized during subsequent trials due to the large amount of time required for deployment and lack of capture of pikeminnow.

During the 2019 electrofishing sampling period, discharge ranged from 130 to 175 cfs at Miranda (USGS Gage 11476500). This range was considerably higher than the long-term median daily discharge for mid-July of approximately 90–100 cfs. Water temperatures measured during electrofishing ranged from approximately 22 to 26°C (72 to 79°F), with higher values being recorded in late afternoon. Water temperature logger data from water year 2019 are included in Appendix A. Underwater visibility during electrofishing trials estimated during co-occurring snorkel surveys ranged from approximately 1.8 to 4.0 m (6 to 13 ft).

Table 6. Sites sampled with boat electrofishing in summer 2019.

Site ID	Rkm (d/s end of site)	Date sampled	Site length (m)	Site description
0101	0.7	7/17/2019	418	Avenue of Giants near confluence
0501	6.4	7/12/2019	440	Gould Bar
1001	12.5	7/16/2019	723	Williams Grove
1401	21.4	7/16/2019	436	Between Miranda and Myers Flat
1801	28.1	7/15/2019	318	Miranda off Maple Hills Rd
2401	37.5	7/18/2019	858	Sylvandale
3101[1]	52.5	7/10/2019	275	Redway Bluffs; just d/s of Garberville
3301[1]	55.5	7/11/2019	140	Randall Sand and Gravel
3301	55.5	7/18/2019	140	Randall Sand and Gravel
4001	67.6	7/19/2019	248	Benbow Drive

[1] Pilot day.

A total of 224 Sacramento Pikeminnow larger than 100 mm standard length were captured during boat electrofishing trials (Table 7). Length frequency varied by site, but most captured individuals were less than 450 mm (Table 7, Figure 10). The weight-length relationship from captured pikeminnow is presented in Appendix B. Pikeminnow smaller than 100 mm were not targeted or processed and very few were captured. Very few fish other than Sacramento Pikeminnow were encountered or captured during boat electrofishing trials. One larval lamprey and three Sacramento Sucker were captured and released.

Table 7. Number of Sacramento Pikeminnow captured with boat electrofishing by site and size class.

Site ID	Size class – standard length (mm)				Total
	101–200	201–300	301–450	>450	
0101	23	7	4	1	35
0501	5	12	16	2	35
1001	14	5	7	0	26
1401	7	1	5	3	16
1801	6	5	1	0	12
2401	0	14	11	1	26
3101[1]	1	0	1	0	2
3301[1]	22	5	0	0	27
3301	3	8	8	0	19
4001	1	11	14	0	26
Total	**82**	**68**	**67**	**7**	**224**

[1] Pilot day.

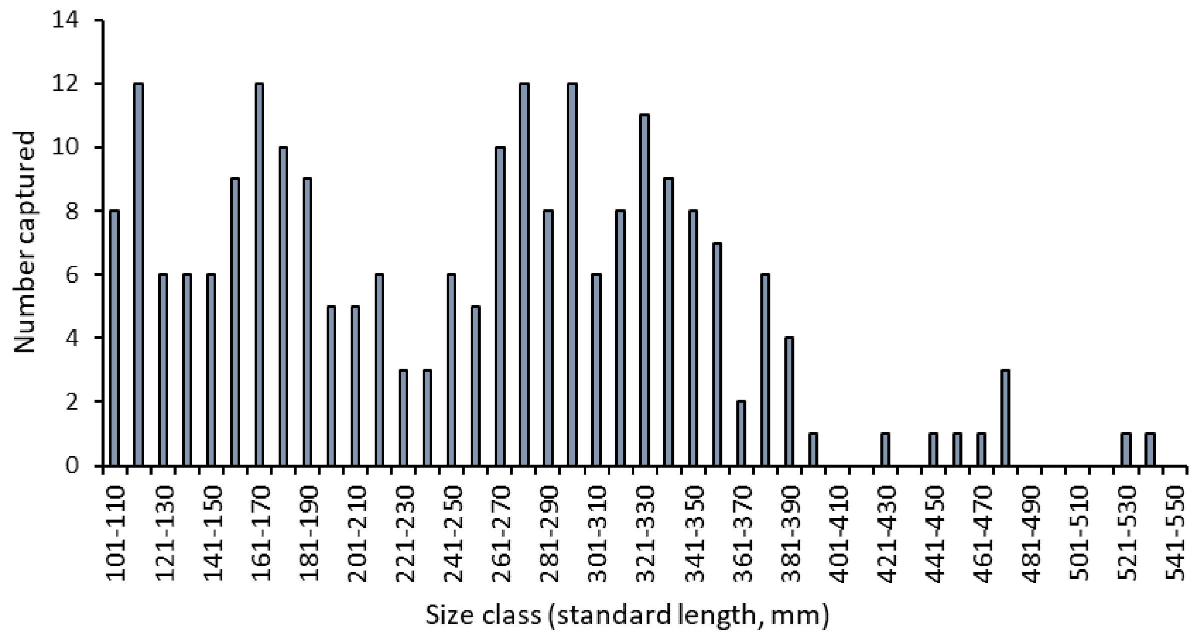

Figure 9. Length frequency of Sacramento Pikeminnow captured with boat electrofishing.

Table 8 lists the two metrics of CPUE of Sacramento Pikeminnow calculated for boat electrofishing. Over the course of all electrofishing trials (excluding pilot days), CPUE based on hours of electrofishing was 5.1 fish/hr for the 101–300 mm size class and 3.1 fish/hr for the >300 mm size class. CPUE based on total number of hours spent at sites was 3.5 fish/hr and 2.1 fish/hr for the 101–300 mm and >300 mm size classes, respectively. CPUE varied considerably between sites and sample dates, but there were no apparent spatial or temporal trends.

Table 8. Catch-per-unit-effort (CPUE) of Sacramento Pikeminnow for boat electrofishing with a throw anode by site and size class.[1]

Date	Site ID	Effort (hrs of electrofishing)	CPUE (# per hr electrofishing)		Effort (hrs at site)	CPUE (# per hr at site)	
			101–300 mm	>300 mm		101–300 mm	>300 mm
7/12/2019	0501	4.0	4.3	4.5	6.5	2.6	2.8
7/15/2019	1801	2.0	5.5	0.5	2.7	4.1	0.4
7/16/2019	1001	1.0	19.0	7.0	2.8	6.8	2.5
7/16/2019	1401	2.3	3.5	3.5	4.2	1.9	1.9
7/17/2019	0101	6.0	5.0	0.8	7.5	4.0	0.7
7/18/2019	2401	2.2	6.4	5.5	2.8	5.1	4.4
7/18/2019	3301	2.3	4.8	3.5	3.5	3.1	2.3
7/19/2019	4001	4.0	3.0	3.5	5.0	2.4	2.8
Total		**23.8**	**5.1**	**3.1**	**34.9**	**3.5**	**2.1**

[1] Not including two days of pilot sampling.

Table 9 compares the number of pikeminnow in each size class counted during snorkel surveys conducted prior to electrofishing to the number captured with electrofishing at each site. Over all sites combined, considerably fewer fish in each size class were captured with electrofishing than observed during snorkeling, ranging from 14% of observed fish in the 101–200 mm size class to 57% in the 301–450 mm size class. However, at some individual sites, more fish in some size classes were captured with electrofishing than observed during snorkeling (Table 9).

Table 9. Percentage of fish in each size class observed during snorkeling that were captured with boat electrofishing at each site.[1]

Site ID	Snorkel date	E-fish date	Sacramento Pikeminnow observed or captured											
			101–200 mm			201–300 mm			301–450 mm			>450 mm		
			Snorkel	E-fish	% caught	Snorkel	E-fish	% caught	Snorkel	E-fish	% caught	Snorkel	E-fish	% caught
0101	7/17	7/17	120	23	19%	14	7	50%	6	4	67%	0	1	–
0501	7/8	7/12	38	5	13%	36	12	33%	12	16	133%	2	2	100%
1001	7/8	7/16	25	14	56%	0	5	–	3	7	233%	0	0	–
1401	7/16	7/16	66	7	11%	49	1	2%	23	5	22%	10	3	30%
1801	7/9	7/15	146	6	4%	31	5	16%	23	1	4%	9	0	0%
2401[2]	7/9	7/18	1	0	0%	6	4	67%	11	4	36%	2	0	0%
3301	7/18	7/18	12	3	25%	39	8	21%	16	8	50%	2	0	0%
4001	7/9	7/19	5	1	20%	8	11	138%	9	14	156%	3	0	0%
Total			**413**	**59**	**14%**	**183**	**53**	**29%**	**103**	**59**	**57%**	**28**	**6**	**21%**

1 Does not include results from the first two days of pilot sampling.
2 Reported snorkel and electrofishing data are for only part of the electrofished site due to inability to associate snorkel data with the entire reach sampled with electrofishing.

3.2.2 Netting and trapping

3.2.2.1 Seining

A total of 187 pikeminnow, the majority of which were <100 mm, were captured at the five sites seined in August 2019 (Table 10). The only pikeminnow larger than 100 mm captured by seining were at Site 1401, where six individuals that were 101–200 mm and 12 that were 201–300 mm were captured, all on the first pass. Total seining effort at each site ranged from 30 to 55 minutes with each pass generally ranging from 10 to 15 minutes. Most fish were captured with the 50-ft seine, but 11 individuals were captured with the 20-ft seine during pilot sampling.

Table 10. Number of Sacramento Pikeminnow of each size class captured by seining at each site, August 19–21, 2019.

Site ID	Rkm	Seine length (ft)	Passes	Total effort (minutes)	Sacramento Pikeminnow captured			
					<100 mm	101–200 mm	201–300 mm	Total
0101	0.7	20	3	46	11	0	0	11
0101	0.7	50	3	30	15	0	0	15
1401	21.4	50	3	38	64	6	12	82
1801	28.1	50	3	45	37	0	0	37
2401	37.5	50	3	55	10	0	0	10
3401	57.5	50	3	35	32	0	0	32

3.2.2.2 Baited box traps

No Sacramento Pikeminnow were captured in the baited box traps. However, underwater video indicated large numbers of smaller (<200 mm) pikeminnow entering and exiting the traps through both the 3.8-cm (1.5-in) mesh sides and trap entrances on the sides (Figure 11). After modifying the traps by covering the mesh walls with smaller mesh bird netting, no fish were observed entering the traps during video monitoring, suggesting they avoided the trap entrances.

At each site where video monitoring was used to monitor the unmodified traps, at least 30 pikeminnow in the 101–200 mm size class were observed in the traps at the same time, and it appeared that considerably more individuals, in total, were attracted to and entered the traps over the course of each deployment. No larger pikeminnow were seen attempting to enter or investigating the traps. Video monitoring showed that the small pikeminnow located the bait quickly, typically entering the traps in large numbers within a few minutes of deployment. Underwater video clearly indicated that chicken liver was the most effective bait at attracting fish to the traps. Fish that entered the traps to investigate the roe and anchovies would typically leave the trap and deployment area soon after entering; whereas fish would feed vigorously on the chicken liver until it was consumed. Plastic mesh bait containers, which allowed pikeminnow to see and actively feed on the chicken liver were more successful at attracting large numbers of fish than hard plastic bait containers with small holes.

Figure 10. Still shot from video monitoring of a baited box trap showing large numbers of 100-200 mm Sacramento Pikeminnow in the trap.

3.2.3 Angling

Angling was conducted opportunistically during two efforts targeting pikeminnow from an oar-frame raft. The first angling effort occurred on February 16, 2018, when the reach between Williams Grove (rkm 13.3) and Gould Bar (rkm 6.3) was floated at a stream flow of 415 cfs. Six pikeminnow, ranging in length from 270 to 301 mm (10.6 to 11.9 in), were captured by three anglers with approximately 6 hours of effort (Table 11). All individuals were captured with nightcrawlers from a single pool and adjacent backwater. The second angling effort was on January 3, 2019, when the reach between rkm 21.7 and Williams Grove (rkm 13.3) was floated. Despite approximately 8 hours of effort by four anglers (primarily with nightcrawlers) in apparently good pikeminnow habitat (deep pools and slow backwaters), no individuals were captured. Fourteen pikeminnow captured as by-catch by a steelhead fisherman during four days of fishing from a drift boat in winter 2017/2018 between Gould Bar (rkm 6.3) and the Eel River confluence (rkm 0.0) were also donated to the project (Table 11). These individuals, ranging in length from 196 to 410 mm (7.7 to 16.1 in) were captured using cured salmon roe and a traditional steelhead drift fishing setup. Gut contents of the pikeminnow captured during these efforts are described in Section 3.3.

Table 11. Winter angling results for the South Fork Eel.

Date	Captured by	Reach start (rkm)	Reach end (rkm)	Bait	Number of anglers	Effort (angler hrs)	Pikeminnow captured	Lengths (standard, mm)
12/4/2017	Steelhead angler	6.3	0	salmon roe	2	unknown	2	251, 396
1/13/2018		6.3	0	salmon roe	2	unknown	5	237, 258, 300, 338, 410
1/14/2018		6.3	0	salmon roe	2	unknown	4	206, 217, 237, 262
2/6/2018		6.3	0	salmon roe	2	unknown	3	196, 241, 341
2/16/2018	This project	13.3	6.3	nightcrawlers	2	12	6	270, 276,280, 296, 301
1/3/2019		21.7	13.3	nightcrawlers	3	24	0	--

3.3 Diet Evaluation

Ninety-five pikeminnow gut samples collected during summer 2019 electrofishing were examined for diet composition, with approximately 30 samples from each size class except the >450 mm class (Table 12). Across all size classes, 55% of the samples contained prey items, while the rest were empty. Of the fish with non-empty gut samples, 79%, 15%, and 12% contained insects, fish, and crayfish, respectively. The percentage of individuals containing insects decreased with increasing pikeminnow length (Table 12, Figure 12). The 301–450 mm size class had the highest percentage of samples containing fish prey. The smallest individual pikeminnow documented eating fish was 290 mm (11.4 in) (Figure 12). None of the fish or fish parts examined from gut contents could be identified to species due to being partially digested. The >450 mm size class had the highest percentage of samples containing crayfish, with the four largest individuals containing only crayfish (Table 12, Figure 12). The smallest individual containing crayfish was 273 mm (10.7 in).

Insects accounted for 100%, 84%, 66% of gut contents by wet weight of pikeminnow in the 101–200 mm, 201–300 mm 301–450 mm size classes, respectively (Table 12). No insects were found in the seven pikeminnow >450 mm. Fish composed 0%, 12%, 34%, and 2% of the weight of the 101–200 mm, 201–300 mm, 301–450 mm, and >450 mm pikeminnow size classes, respectively. Crayfish were the dominant prey item by frequency and weight in the >450 mm size class and rare or absent in the other size classes.

The gut contents of 14 of the 20 Sacramento Pikeminnow captured during winter angling (Table 11) were examined. All winter gut samples were empty except for a small amount of an undiscernible white, slime-like substance that had not been evacuated.

Table 12. Gut contents of Sacramento Pikeminnow collected during summer 2019 electrofishing. Frequency of occurrence and percent of total wet weight of major prey items in non-empty samples are presented for each size class.

Size class (standard length, mm)	Number of samples	Number non-empty	Percent non-empty	Frequency of occurrence in non-empty samples			Percent wet weight (pooled by size class)		
				Insects	Fish	Crayfish	Insects	Fish	Crayfish
101–200	30	15	50%	100%	0%	0%	100%	0%	0%
201–300	28	20	71%	85%	10%	10%	84%	12%	4%
301–450	30	11	37%	82%	45%	0%	66%	34%	0%
>450	7	5	71%	0%	20%	80%	0%	2%	98%
Total	**95**	**52**	**55%**	**79%**	**15%**	**12%**	**32%**	**9%**	**59%**

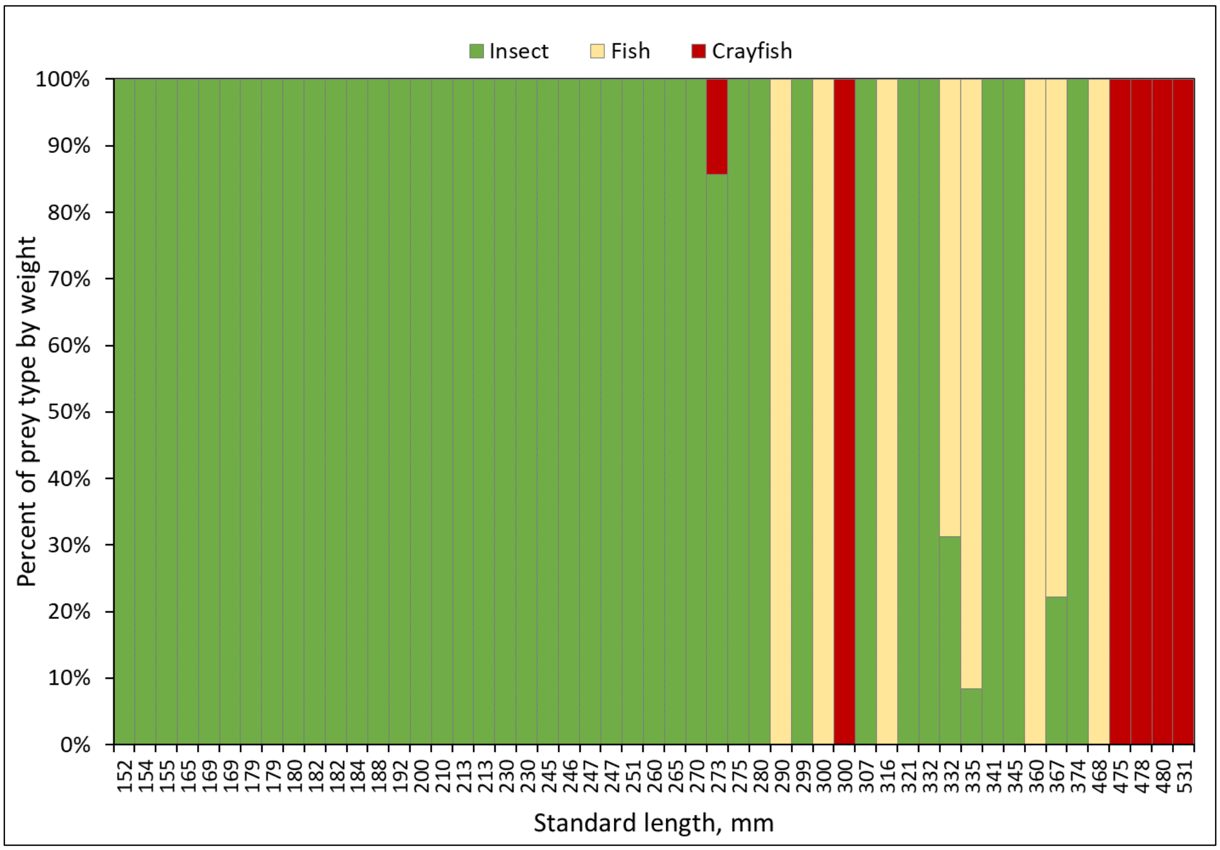

Figure 11. Percent of major prey types, by weight, in gut samples of individual Sacramento Pikeminnow ordered by standard length. Empty samples not shown.

4 DISCUSSION

4.1 Population Monitoring

The large numbers of Sacramento Pikeminnow and very small numbers of other species counted during summer 2018 snorkel surveys indicate that it is by far the dominant fish species in the 105-km mainstem South Fork Eel River Monitoring Reach. Pikeminnow were widely distributed, with no apparent longitudinal pattern in linear densities. This finding suggests density in the summer is generally driven by distribution of local habitat features such as depth and cover rather than longitudinal position within the Monitoring Reach. In general, the greatest numbers of pikeminnow >300 mm were found in habitat units with maximum depth greater than about 2.4 m (8 ft), but some locations as shallow as 1.2 m (4 ft) held several large pikeminnow and some deep pools had none. Our snorkel surveys also documented specific habitat units with high densities of large pikeminnow, highlighting the value of using population monitoring to identify "hotspots" to target with suppression efforts.

This study demonstrates the advantage of using a GRTS site selection approach for efficiently estimating the pikeminnow population over a relatively long study reach. Sub-reach counts and abundance estimates should be considered minimum estimates of abundance due to imperfect observation probability during snorkeling, especially in deep pools or locations with complex cover. The potential for undercounting was demonstrated when comparing snorkel counts to electrofishing captures at the same site in summer 2019. At a few sites, more individuals of a given size class were captured with electrofishing than seen while snorkeling, suggesting either not all fish present were observed, or fish moved into the sampling area between snorkeling and electrofishing (Table 9). Estimating observation probability of snorkel counts would improve understanding of pikeminnow abundance. Depletion electrofishing was initially considered for this study to estimate true population size and compare with snorkel counts but the approach was abandoned due to logistical challenges of setting block nets in such a large channel. Another potential approach for estimating observation probably is conducting a mark-recapture population estimate in a snorkeled habitat unit or reach.

Despite the potential for underestimating the true population, if applied consistently snorkel surveys provide a reasonable estimate of relative pikeminnow abundance in the Monitoring Reach that can be compared with result of future surveys to detect relatively large changes in the population, such as declines anticipated to occur following a large-scale coordinated suppression effort. Notably, recent monitoring in the upper South Fork Eel River in the reach between Standish-Hickey SRA and Rattlesnake Creek has shown considerable interannual variability in counts of pikeminnow in different size classes (Higgins 2020). Annual summer fish monitoring in the upper Eel River at sites downstream of Cape Horn Dam between 2005 and 2019 has also shown interannual fluctuation in pikeminnow densities, with densities generally being higher in dry water years and lower in wet water years (PG&E 2020a). The mechanisms behind this observed variability are unclear but may be related to increased survival and recruitment following dryer water years. An alternative explanation is that observed differences in abundance between years are due in part to annual differences in spatial distribution of the population and timing of seasonal movements (immigration and emigration into and out of the surveyed area), driven by stream flow and water temperature. Harvey and Nakamoto (1999) documented large-scale seasonal movements of adult pikeminnow, finding that individuals tagged in the South Fork Eel River at Standish-Hickey SRA moved downstream approximately 25 rkm (15.5 mi) at the onset of high winter flows prior to returning to the vicinity of their tagging locations the following spring. Recent research has revealed that timing of annual movements of adult pikeminnow into upper reaches of the South Fork Eel River (near Elder Creek, rkm 139) is driven in part by water temperature, with later arrival in the reach in years with cooler water temperatures (P. Georgakakos, pers. comm., 27 March 2019). Describing the mechanisms behind interannual variability in abundance is important for improving interpretation of population monitoring data, for understanding the roles of flow and water temperature in pikeminnow seasonal movements and population dynamics, and for developing effective management strategies.

4.2 Evaluation of Suppression Strategies

4.2.1 Boat electrofishing

Overall, boat electrofishing trials demonstrated the utility of the method for capturing considerable numbers of pikeminnow >100 mm in the South Fork Eel River. A throw anode was used for most of the trials after an initial, limited comparison with the traditional boom-mounted anode setup suggested the throw anode was generally more effective at capturing large pikeminnow in much of their preferred habitat. During limited trials, the boom-mounted system proved to be relatively ineffective for capturing larger, more wary individuals, possibly because it was necessary to maneuver the boat directly above them to apply sufficient current to stun them. The loud noise produced by the boat motor and generator, along with the clear water and continuous shocking with a large electrical field, may have spooked many individuals before they could be stunned. Furthermore, the two boom anodes emanating from the boat were cumbersome to maneuver around instream boulders and overhanging trees. Removing the booms from the boat for the throw anode setup increased maneuverability and the ability to sample habitats associated with thick overhead cover or rock crevices. Additionally, the throw anode increased the distance from the boat that could be effectively sampled [6–9 m (20–30 ft)] compared with the stationary booms [1.5–3 m (5–10 ft)] and allowed observed fish to be rapidly and precisely targeted. The throw anode could also more effectively sample deeper water [(less than approximately 3 m (10 ft)] compared with the traditional anodes [(less than approximately 1.8–2.4 m (6–8 ft)].

The throw anode was particularly effective when water clarity was relatively high and large fish could be easily seen and targeted. However, it was less effective in situations where wind, sun glare, or algae limited visibility and traditional anodes may be preferred in these cases. One advantage of the traditional anode is that it creates a larger electrical field and allows for more continuous shocking relative to the throw anode, which samples a relatively small area and takes time to pull in and re-deploy between throws. Repeatedly throwing and retrieving the anode also requires considerable energy expenditure compared with the boom-mounted anodes. The larger electrical field and continuous shocking allowed by the boom-mounted anodes appeared to be more effective at capturing schools of smaller pikeminnow, which were less spooked by the boat and typically in shallower water. Various other projects have captured significant numbers of larger pikeminnow in the South Fork Eel River or similarly sized rivers using a traditional anode setup (e.g., Nakamoto and Harvey 2003, PG&E 2020a) and additional comparison of this method with the throw anode setup is warranted. Ultimately, the relative success of each method likely depends on the site-specific conditions and setting up the boat to allow switching between the two setups relatively quickly is recommended.

Other potential electrofishing approaches should also be tested and considered for removing pikeminnow. In particular, using a raft equipped with an electrofisher is needed to access many reaches of the South Fork Eel River that are not accessible by jet-boat. Another approach that could be useful in certain situations where boat access is limited is shore-based electrofishing with a throw anode. Bureau of Land Management (BLM) with assistance from CDFW, J.B. Lovelace & Associates, and Stillwater Sciences recently used this technique to remove adult pikeminnow from a remote location in the North Fork Eel River where launching a boat was not feasible. The electrofisher was set up on a rock outcropping adjacent to where three large, adult pikeminnow were known to be holding and all three fish were stunned with the throw anode and captured with dip nets from shore. Utilizing fyke or trap nets in combination with electrofishing to capture fish fleeing the electrical field also warrants additional investigation. This technique was tested once during pilot efforts but abandoned due to lack of pikeminnow capture, considerable amount of time required for deployment, and need to focus on other project objectives.

Lessons learned during 2019 boat electrofishing trials will be applied during future efforts. For example, during the summer, early morning sampling is preferred to minimize encountering the public who commonly recreate at the easily accessible sites where a boat trailer can be launched. In general, the public was supportive of the project and cooperative, but some individuals were upset about staying out of the water during electrofishing. Additionally, when conducting boat electrofishing at a site with multiple habitat units, the downstream most unit should generally be sampled first to minimize: (1) the potential for impacting downstream water clarity and (2) the potential for *schreckstoff* released from injured pikeminnow to cause individuals downstream to flee or hide and avoid capture.

CPUE values computed from trials of boat electrofishing with a throw anode can be used to provide a coarse estimate of the effort required to remove target numbers of pikeminnow for a suppression program. For example, assuming the overall CPUE for fish >300 mm (3.1 fish/hr of electrofishing) could be achieved, it would take approximately 1,300 hours for one boat crew to remove the 3,990 pikeminnow >300 mm estimated to occur in the Study Reach in 2018 (Table 2). There are several reasons, however, why these CPUE values may not be representative of what could be achieved in a larger scale electrofishing suppression effort. First, CPUE is expected to decline as more fish are removed and densities in the Study Reach decline. Thus, the effort required to remove a large portion of the pikeminnow population would be greater than predicted from electrofishing sites with a "full" population. Second, CPUE values reported herein are based on that achieved with a jet boat at locations in the Study Reach downstream of the East Branch South Fork Eel River with high quality pikeminnow habitat that are accessible by trailer and boat in the summer. There are long, inaccessible sections of the Study Reach that are not accessible by jet boat during low flows. These reaches would need to be sampled by floating with an electrofishing raft and CPUE from this non-motorized approach could be lower. For example, time would be required to shuttle a vehicle to the takeout and long sections of poor pikeminnow habitat may need to be floated to access preferred habitats to sample. Additionally, CPUE values from this study were from early summer trials in a wet water year with stream flow well above the long-term median and may not be representative of lower stream flows later in the summer or a dryer water year. It is possible that CPUE would be higher at lower stream flows when fish are concentrated, but fewer habitat units are expected to be accessible by jet boat at lower stream flows.

There are also several reasons why boat electrofishing CPUE values from this study were lower than what could be achieved under a directed suppression program. First, overall efficiency and time available for capturing fish can be expected to increase with increased field crew experience setting up and implementing the method. Second, multiple passes were conducted at most sites with diminishing numbers of fish captured in later passes. Conducting fewer passes and sampling more locations, with a jet boat or by raft, could increase overall CPUE. Finally, during electrofishing trials, time was spent recording various data and shuttling captured fish to processors on shore, which may not be needed for a suppression program.

Recent boat electrofishing efforts conducted by PG&E and contractors using a traditional boom-mounted anode setup in Van Arsdale Reservoir, where high densities of pikeminnow are known to occur, demonstrate the potential effectiveness of the approach for removing large pikeminnow (PG&E 2020b). During their most successful suppression effort, PG&E (2020b) captured 156 pikeminnow >300 mm in 5 hours of boat electrofishing, a CPUE of 31.2 fish/hr. Raft electrofishing efforts conducted in adjacent reaches of the upper Eel River with a tote-barge setup and long anode poles resulted in considerably lower CPUE values, ranging from 0 to 2.6 fish/hr (PG&E 2020b).

Understanding of effort and cost required to remove target numbers of pikeminnow via electrofishing as part of a suppression program can be refined through: (1) more extensive boat (and possibly raft) electrofishing suppression efforts planned for Phase 2 of this project and (2) coordinating with PG&E to calculate CPUE from boat electrofishing suppression efforts in the upper Eel River.

CPUE from boat electrofishing could be increased by electrofishing at dusk or nighttime, since large pikeminnow are thought to be more active as dusk and dawn and may move into shallower water (Brown and Moyle 1981, Harvey and Nakamoto 1999). Harvey and Nakamoto (1999) found that, during the summer, adult Sacramento Pikeminnow that held in large pools during the day commonly moved through adjacent riffles into shallower pools or runs at night, before returning to the large pools the next day. In October, they found that many fish occupied a pool body during the day and moved into either the pool head or pool tail at night. If these behaviors are pervasive, more adult pikeminnow may be susceptible to electrofishing at night, assuming these shallower habitats can be accessed and sampled by boat. Stunned pikeminnow may also be more visible to netters in boat floodlights at night compared to the day when surface glare or shadows can limit visibility. Another advantage of nighttime electrofishing on the South Fork Eel River in the summer is that it avoids decreased efficiency related to overlap with swimmers and others recreating during the day. PG&E (2020) conducted limited nighttime electrofishing in Van Arsdale Reservoir in 2019 but found that CPUE was higher during the daytime. However, other studies indicate nighttime electrofishing can be more effective at capturing predatory fish at night (e.g., Paragamian 1989, Pierce et al. 2001, Smith 2017, Stillwater Sciences 2019) and it should be further tested in the South Fork Eel River.

In addition to evaluating CPUE of boat electrofishing, understanding the fraction of the population that can be removed from a sampled location with a given amount of effort is important for evaluating feasibility and designing an effective suppression program. A comparison of pikeminnow counts from snorkel surveys with the number captured by subsequent electrofishing at the same site suggests that only a fraction (typically about 15–60% depending on size class) of fish observed were typically removed. However, these findings should be viewed with caution due to uncertainty in observation efficiency of snorkeling. Mark-recapture should also be considered to improve the accuracy of pikeminnow abundance estimates at sampled sites and determine the fraction of the population that can typically be removed with boat electrofishing (during the mark event).

4.2.2 Netting and trapping

4.2.2.1 Seining

Limited trials demonstrated that seining has potential to be an effective method for capturing large numbers of small pikeminnow (<100 mm) and smaller numbers of those in the 101–200 mm and 201–300 mm size classes with relatively low effort. Seining was limited by the relatively small net used and worked best in locations that were relatively shallow [<1.2 m (<4 ft)] and free of obstructions. A larger [≥ 30 m (≥100 ft] and deeper [≥ 1.8 m (≥6 ft)] seine is expected to result in more consistent capture of pikeminnow >100 mm and should be tested. Harvey and Nakamoto (1999) were able to capture five pikeminnow >375 mm (14.8 in) with a 45 m x 3 m (150 ft x 10 ft) seine at a pool in Standish Hickey SRA, but reported that seining was less effective at the downstream sites they sampled due to the larger channel and presence of woody debris. A 120 m x 6 m (400 ft x 20 ft) seine pulled by a jet boat was recently deployed at a location in the mainstem Eel River for an effort to support salmon and steelhead monitoring (Kajtaniak and Gruver 2020). All pikeminnow captured during that limited effort ranged from 180 to 240 mm (7.1 to 9.5 in), but the effort demonstrated that the gear and technique has potential to catch larger individuals.

Baiting the area to be seined with chicken liver appeared to attract smaller pikeminnow and increase catch. In general, most fish were captured on the first pass with few or none captured on the second and third passes. It is possible that the decreased capture was related to release of *schreckstoff* by individuals that became tangled in the net and injured.

4.2.2.2 Baited box traps

Although baited box traps were not successful at capturing pikeminnow, trials demonstrated that box traps baited with chicken liver have potential to rapidly capture large numbers of smaller pikeminnow (<200 mm). Modifying the trap mesh prevented fish that entered the traps from exiting through the trap walls, but they escaped through the side entrances during retrieval of the traps. With additional modifications of the trap entrances and testing, this gear or similar baited traps could be used to remove large numbers of small pikeminnow as part a larger suppression program. The lack of success capturing larger individuals (>200 mm) may be due to their greater wariness around the traps. Numerous larger pikeminnow were confirmed to be present in several of the sampled pools by snorkeling, but video monitoring of the traps did not show them attempting to enter or investigate the bait. Additional nighttime sampling, different baits such as crayfish, and/or different style passive fish traps may be more successful at capturing larger individuals. Recent studies indicate that baited fish traps can be an effective capture method for large predatory species such as striped bass (Mortensen 2014). Passive methods such as baited traps have an additional advantage of allowing nearby habitats to be simultaneously sampled with other methods such as seining or electrofishing, increasing the overall number of fish that can be captured per unit of time expended by a field crew.

4.2.3 Angling

Results from angling trials demonstrate that considerable effort is likely required to capture relatively small numbers of Sacramento Pikeminnow in the South Fork Eel River during the winter. Capture of several individuals at one location and no individuals at numerous locations with high quality pikeminnow habitat suggest that pikeminnow are either patchily distributed or feed more actively during certain periods. All pikeminnow captured ranged in size from approximately 200–400 mm (8–16 in), despite the observation of large numbers of smaller pikeminnow during summer snorkel surveys (this study) and winter snorkel surveys (S. Ricker, pers. comm., 28 February 2020). Both night crawlers and salmon roe appeared to be an effective bait. Based on the finding from box trapping that pikeminnow were highly attracted to chicken liver, it should be tried as a bait in the future. Other natural baits that should be tested include white cheddar cheese and Mormon crickets, which along with chicken liver are the most effective baits used in the Northern Pikeminnow sport-reward program on the Columbia River (S. Williams, PSMFC, pers. comm., 27 March 2019). Various artificial baits imitating smaller fish are also known to be effective and results of summer diet evaluation (Section 3.3) suggest that crayfish imitations may work well for catching larger pikeminnow.

Few conclusions can be drawn regarding CPUE achievable from angling based on the limited and opportunistic efforts from this study. All effort was in the winter and in the reach downstream of rkm 22 and therefore not necessarily applicable to understanding potential effectiveness of angling in the summer or in other reaches. Various anecdotal accounts indicate that pikeminnow may be more easily captured with angling in spring or summer than in winter. Increased metabolic rate and decreased gastric evacuation time with increasing temperature suggests that pikeminnow would be feeding more actively during the summer (Vondracek 1987). Additional efforts are needed to quantify CPUE of summer angling and compare it to that of other methods such as electrofishing. For example, if two anglers can catch half as many pikeminnow per hour as a 4–5 person boat electrofishing crew, then angling could be equally viable as a suppression method and would be considerably less costly. Moreover, angling can be applied to remove large fish from deep pools where other methods such as electrofishing have limited effectiveness.

Angling has potential to be an important and affordable component of a multipronged pikeminnow population suppression program, particularly if the recreational fishing community is involved. Anglers consistently capture pikeminnow in the lower South Fork Eel and lower mainstem Eel River while fishing for steelhead. Initially, basic creel surveys of steelhead anglers could be used to describe CPUE of pikeminnow by-catch and potential for removal during the winter. Even if CPUE is relatively low, the large amount of effort could result in removal of significant numbers of pikeminnow. Supportive anglers and guides could also provide captured fish to support additional evaluation of winter diet. In addition to taking advantage of existing winter effort, regulatory changes or a sport-reward program that encourage anglers to target and retain pikeminnow during existing fishing season (fourth Saturday in May through March 31 for South Fork Eel River downstream of Rattlesnake Creek) should be considered. The cost of promoting and implementing such programs should be compared with cost of other suppression approaches in terms of cost per fish removed. A sport-reward program has been applied to remove large numbers of native Northern Pikeminnow from reservoirs in the Columbia River since 1991 (Winther et al. 2020) and this program could inform feasibility of developing a similar program for the Eel River. Annual pikeminnow derbies—which have previously been held in the Eel River basin in the mid-2000s (Friends of the Eel River 2005)—are another relatively low cost way to remove pikeminnow and engage the public that should be considered as a component of a suppression program.

4.2.4 Other potential population suppression methods and strategies

Ultimately, a successful population suppression program for Sacramento Pikeminnow in the Eel River is expected to require a multipronged approach, applying methods that are most suitable for removing target size classes during different seasons and stream flow conditions and from habitats with variable characteristics (depth, flow, cover, etc.). Several other methods and strategies not tested in this study have promise for controlling pikeminnow the Eel River watershed and are discussed here. Importantly, for all potential methods, it is critical to understand and minimize potential adverse impacts to native fishes. If significant impacts are unavoidable, then the methods should be abandoned in favor of less impactful approaches.

Spearfishing, either by free diving or with scuba gear, also warrants evaluation in terms of CPUE for a potential role in a larger pikeminnow suppression program. If conducted by well-trained divers, this method could eliminate bycatch of non-target species and allow removal of pikeminnow from deep or complex habitats where other gears may not be effective. However, the escape behavior triggered by release of *schreckstoff* from injured pikeminnow may limit effectiveness of this approach. Another approach that avoids both non-target bycatch and the *schreckstoff* response is capturing fish at night using dive lights and hand nets. This approach has proven to be effective at capturing various juvenile salmonids and large, adult cutthroat trout (S. Rizza, Stillwater Sciences, pers. comm., 15 May 2020) and merits testing for collecting pikeminnow diet samples. Additional netting and trapping techniques not tested in this study should also be explored for application to pikeminnow in the Eel River basin. For example, a floating trap net was found to be effective for catching Northern Pikeminnow at certain sites in the Columbia River (Porter 2013).

Targeting pikeminnow during diel or seasonal migrations is another strategy that should be explored. As described above, some adult pikeminnow make diel movements between deep pools and adjacent shallower locations, moving both upstream and downstream and sometimes moving over 500 m (1,640 ft) from daytime locations (Harvey and Nakamoto 1999). Larger-scale seasonal movements of adult pikeminnow has also been documented, with individuals tagged in the upper reaches of the South Fork Eel River moving downstream approximately 25 km (15.5 mi) in the fall before and moving back upstream in the spring (Harvey and Nakamoto 1999). Snorkel surveys conducted in February 2020 by CDFW biologists in the mainstem South Fork Eel River (during an unseasonably dry period with clear water) did not detect any pikeminnow >100 mm in the reach between Cedar Creek (rkm 113) and Richardson Grove SP (rkm 74) (S. Ricker, pers. comm., 28 February 2020). While only portions of the reach were sampled and some fish could have been missed in deep, complex pools, this survey generally supports the findings of Nakamoto and Harvey (1999), suggesting that many adult pikeminnow that spend the summer in the upper reaches of the South Fork Eel River likely move downstream and overwinter in lower reaches. Utilizing passive trapping techniques such a channel spanning fyke net or a weir leading to a trap has potential to intercept pikeminnow during these diel or seasonal movements. Additional winter snorkel surveys to describe winter distribution of adult pikeminnow in the South Fork Eel River and deploying a weir or stationary sonar device to describe upstream movement timing in the spring would inform design of this potential suppression approach.

Research to locate spawning or feeding aggregations of pikeminnow would also be valuable, since these locations could be targeted with suppression measures. Key spawning locations in the South Fork Eel River watershed are largely unknown. Larval fish sampling conducted by Harvey et al. (2002) suggests that spawning is relatively widespread, but at least some spawning occurs in tributaries and some locations could be hotspots (e.g., Salmon Creek, where high densities of larval pikeminnow were captured). It has also been suggested that Sacramento Pikeminnow in the Upper Eel River congregate at tributary confluences to feed on outmigrating juvenile salmonids (SEC 1998). This behavior warrants further investigation. If large numbers of pikeminnow congregate at certain times and locations, they could be targeted for removal with electrofishing, netting, or other removal methods. Such spawning or feeding congregations could be located by snorkeling or tagging adults and tracking them during the spring spawning and salmonid outmigration periods.

Other innovative population suppression strategies for Sacramento Pikeminnow in the Eel River that do not involve direct removal should also be assessed. In particular, feasibility of the Trojan Y chromosome strategy should be evaluated. This strategy involves releasing pikeminnow that have been altered to have two Y sex chromosomes, either egg-producing YY females or sperm-producing YY "supermales". When the YY females mate with normal XY males, all resulting offspring are male and half of those are YY supermales that produce all male offspring. Over time, the sex ratio of the population is heavily skewed towards males and the reproductive capacity of the population is greatly diminished. This approach has been evaluated for Brook Trout (Schill et al. 2016) and the feasibility of applying it to Sacramento Pikeminnow in the Eel River is being considered by Humboldt State University researchers and their partners. Both biological information such as age and growth analyses and CPUE data collected from this study and planned for Phase 2 can be used to support this much needed feasibility study.

4.3 Diet Evaluation

Examination of diet samples from this study indicated that fish composed a relatively small percentage of pikeminnow diets in the reach downstream of East Branch South Fork Eel River during the summer, except for the 301–450 mm size class where fish were found in 45% of non-empty gut samples and made up 34% of the diet by weight. No larval lamprey (ammocoetes) or salmonids were confirmed in the gut samples examined. Based on species composition of potential prey-sized fish observed during snorkel surveys in the sampled reach in the summer, fish consumed by pikeminnow were likely roach or smaller pikeminnow rather than salmonids. Insects made up the majority of diet by weight in all size classes except the >450 mm class, which had a diet dominated by crayfish. The small number of winter gut samples collected were insufficient to draw any conclusions about winter diet, but it is notable that all were empty.

Summer diet results from this study were similar to those reported for the South Fork Eel River in the mid-1990s by Nakamoto and Harvey (2003), who found an overall decrease in insects and an increase in fish in pikeminnow diet with increasing size. However, they did not report crayfish in their samples and found a considerably higher proportion of fish in the summer diet of pikeminnow in the South Fork Eel compared with this study. Nakamoto and Harvey (2003) reported that, on average, fish composed nearly 70% of the summer diet by weight of pikeminnow >250 mm, with steelhead, Sacramento Sucker, pikeminnow, and roach being the most common prey species, respectively. They also reported larval lamprey as a frequent prey item with a greater frequency of occurrence in the diet during winter and spring than in the summer. The differences in fish consumption between our study and the Nakamoto and Harvey (2003) study is likely explained by differences in sampling locations: they collected diet samples from sites in cooler upstream reaches containing higher numbers of juvenile steelhead. Additionally, the composition and abundance of available prey species has likely changed considerably in the 20 years between studies.

Brown and Moyle (1997) also described Sacramento Pikeminnow summer diet from sites across the Eel River basin and generally found a decrease in insects and an increase in fish and crayfish with increasing size. Like this study, crayfish were an important part of the diet of the largest individuals, although very few fish >200 mm were sampled. Brown and Moyle (1997) found salmonids in the diet of pikeminnow ranging in size from approximately 100–300 mm with frequency of salmonid occurrence increasing with increasing size. They also documented larval lampreys in a small percentage of pikeminnow in the 100–200 mm size range and sucker and roach in pikeminnow in the 50–100 mm size range.

The relatively few and spatially and seasonally restricted diet samples we collected from the South Fork Eel River downstream of the East Branch during the summer provide a limited portrayal of the overall diet of Sacramento Pikeminnow and their impact on native fishes. While our results indicate little to no predation on salmonids, very few salmonids persist through the summer in the sampled reach due to high water temperatures. Steelhead are much more common in upstream reaches of the South Fork Eel River, Coho Salmon are restricted to cold tributaries with water temperatures significantly lower than that preferred by pikeminnow, and juvenile Chinook Salmon generally complete their outmigration to the estuary and ocean by early summer (CDFG 2010). For this reason, collection of diet samples (1) in the summer in cooler reaches of the South Fork Eel River where more juvenile steelhead are present, and (2) in the winter and spring outmigration periods when pikeminnow are more likely to encounter these species in high abundance is needed for describing overall impacts of predation.

Additionally, gut content examination only provides a point-in-time depiction of an individual fish's diet, which may not be representative of average diet over a longer period. Since adult Sacramento Pikeminnow can exhibit diel feeding patterns—feeding mainly at dusk, night, or early morning (Brown and Moyle 1981, Harvey and Nakamoto 1999)—it is possible that much of the gut contents from samples collected during this study had been digested by the time of capture. Vondracek (1987) found that digestive rate of juvenile Chinook Salmon in Sacramento Pikeminnow guts increased with increasing temperature and estimated that evacuation of gut contents (i.e., gastric evacuation) occurred after 14 hours at 20°C (68°F). Petersen and Barfoot (2003) found that Northern Pikeminnow could completely digest a juvenile salmon in as few as 10 hours at 18°C (64°F). A consumed fish is likely unidentifiable due to digestion even sooner and smaller prey items that lack hard parts such a lamprey ammocoetes are likely digested and unidentifiable even more quickly. Because of the rapid digestion of prey items at water temperatures occurring in the summer, most of the identifiable prey from our samples were likely consumed within several hours of capture. Consequently, relying on gut contents alone could lead to erroneous conclusions about overall pikeminnow diet composition.

To address the limitations of the diet evaluation conducted for the current study the following are recommended for Phase 2 of this project.

- Further examination of the diet of pikeminnow collected during the winter and spring, when they are more likely to encounter salmonids and potentially lamprey.
- Examination of the diet of pikeminnow collected in the South Fork Eel River upstream of the East Branch, where they are more likely to encounter juvenile steelhead during the summer.
- Isotopic diet analysis of pikeminnow muscle tissue. Measuring the ratios of the stable isotopes δ13C and δ15N in tissue samples will allow description of the relative contribution of major prey items (e.g., juvenile salmonids, lamprey ammocoetes, other fishes, macroinvertebrates, crayfish) over a longer time period than gut content examination (weeks or months instead of hours), thereby avoiding errors associated with diel differences in feeding and digestion of stomach contents. By providing more accurate estimates of diet composition, isotopic analysis will improve the accuracy of bioenergetics modeling aimed at assessing the magnitude of pikeminnow predation on native fishes in the Eel River.

Another promising approach for improving understanding of pikeminnow diet that should be considered involves genetic analysis of gut contents using environmental DNA (e-DNA) techniques to document presence of species of interest. Jarrett et al. (2019) applied this technique to detect Sacramento Pikeminnow predation on juvenile steelhead in Chorro Creek on the Central Coast of California. They were unable to detect steelhead through visual examination of gut contents but detected steelhead DNA in 7 of 39 gut samples. This technique is not currently planned for upcoming pikeminnow diet evaluations on the South Fork Eel River, but should be considered if additional funding becomes available, since it would allow for greater detection of target prey-species compared with both direct gut sample examination and isotopic analysis.

5 RECOMMENDATIONS

This section lists key recommendations for Sacramento Pikeminnow population monitoring, suppression strategies, research, and management in the South Fork Eel River. Refer to Section 4 for additional discussion of these topics. Some of these recommendations are currently planned for Phase 2 of the project in 2020 and 2021; however, some are beyond the scope and resources of the project and will require additional funding or involvement from other Eel River stakeholders to achieve.

5.1.1 Population monitoring

Key recommendations for improving monitoring of pikeminnow abundance and distribution and interpretation of monitoring data include:

- Estimate observation efficiency of summer snorkel counts to improve understanding of true population size. Observation efficiency can be estimated by comparing snorkel counts to subsequent mark-recapture population estimates of pikeminnow conducted at the same location with electrofishing.
- Explore ways to improve pikeminnow abundance estimates in the Monitoring Reach by incorporating the relationship between pikeminnow counts and sub-reach-scale habitat variables (such as length of riffle or deep pool habitats) into estimates.
- Conduct studies to improve understanding of pikeminnow seasonal and annual movements. Such studies would aid in interpretation of annual abundance estimates in the Monitoring Reach. It is particularly important to understand whether annual, large-scale differences in pikeminnow movement timing and distribution related to stream flow and water temperature could drive observed differences in abundance estimates in the Monitoring Reach between years. Acoustic or radio telemetry could be used to describe seasonal and annual movement patterns of pikeminnow within and outside of the Monitoring Reach. Interannual movements could also be documented by tagging large numbers of pikeminnow captured at sites within and outside of the Monitoring Reach with uniquely colored and individually numbered floy tags, releasing them, and resighting or recapturing them a year later during snorkel surveys or suppression activities, respectively.
- Coordinate with other Eel River stakeholders to conduct similar annual surveys to monitor the pikeminnow population in other portions of the Eel River basin to improve overall understanding of pikeminnow population trends. Population monitoring is already being conducted in select reaches of the South Fork Eel by Eel River Recovery Project, in the North Fork Eel River by BLM, and in the upper mainstem Eel River by PG&E. Additional surveys in other portions of the basin could be done on a large scale (similar to the Monitoring Reach) using a GRTS sampling scheme or in shorter index reaches, depending on resources and access constraints.

- In conjunction with larger-scale pikeminnow suppression efforts, work with Eel River stakeholders to monitor abundance and survival of key native prey species in the Study Area to help understand their population response to pikeminnow removal and evaluate the success of the suppression program.

5.1.2 Suppression strategies

Specific recommendations for further evaluation and implementation of the pikeminnow suppression methods tested in this study, as well as other potential suppression strategies, are listed below. Refer to Section 4.2 for additional discussion of these recommendations.

In general, a multi-pronged suppression program that removes as many pikeminnow as possible from multiple age classes is needed. While boat electrofishing in the summer is expected to be one of the most effective approaches, a suite of other approaches targeting other size classes, habitats, and seasons will maximize impact of a suppression program. Importantly, a predator removal approach that only targets adult fish may result in reduced predation on younger age classes and less intraspecific competition, leading to more rapid growth, maturation, and abundance of younger size classes (Zipkin et al. 2008, 2009). For this reason, methods that target smaller size classes should be used in combination with removal of larger adults.

5.1.2.1 Boat electrofishing

- Conduct additional tests of the traditional and throw anode setups and settings for boat electrofishing under different habitat and environmental conditions to maximize catch-per-unit effort and better describe the most suitable conditions for utilizing different setups.
- Improve understanding of the fraction of the population that can be removed from a sampled location using boat electrofishing. Mark-recapture techniques can be used to estimate the pikeminnow population at sampled sites and determine the fraction of the population that can typically be removed with boat electrofishing (during the mark event). This estimate would improve understanding of the population-level impacts of suppression efforts and help determine whether multiple efforts are warranted at a site in the same season.
- Refine estimates of CPUE from boat electrofishing through more extensive boat electrofishing suppression efforts planned for Phase 2 of this project. Refined CPUE estimates would improve comparisons with other gear types and aid in understanding of level-of-effort needed to remove target numbers of pikeminnow.
- Coordinate with PG&E to calculate CPUE from boat electrofishing suppression efforts in the upper Eel River.
- Conduct raft-based electrofishing in portions of the Study Reach not accessible by jetboat to test the feasibility and effectiveness of the approach in the South Fork Eel River. This work would ideally be conducted in July, before flows become too low to float, but after juvenile salmonids have left the portion of the Study Reach where electrofishing is currently permitted (downstream of the East Branch South Fork).
- Evaluate the feasibility and effectiveness of boat electrofishing at night on the South Fork Eel River compared with daytime. For this comparison, several sites would be electrofished during the day and all fish released. The site would be revisited at night (ideally 1–2 days later to allow the fish to recover and redistribute) and sampled with the same amount of effort.

5.1.2.2 Netting and trapping

- Test effectiveness of larger and deeper seine nets [e.g., 30 m x 2.4 m (100 ft x 8 ft)] for capturing pikeminnow in the South Fork Eel River. Consider utilizing a kayak or small boat to help pull the seine through deeper habitats.
- Conduct additional trials with baited box traps modified to encourage pikeminnow entry and with finer mesh to retain smaller pikeminnow size classes (< 200 mm).
- Test other styles of baited fish traps, such as large minnow traps, for capturing pikeminnow.
- Evaluate effectiveness and cost of other passive netting and trapping techniques, such as floating trap nets.
- Evaluate effectiveness of capturing pikeminnow at night with hand nets as a means for removal or collection of diet samples.

5.1.2.3 Angling

- Test other natural (e.g., white cheddar cheese and Mormon crickets) and artificial baits (e.g., crayfish imitations) for effectiveness at capturing different size classes of pikeminnow.
- Test effectiveness (CPUE) of angling during the spring and summer when pikeminnow are expected to be feeding more actively and compare it with other suppression methods.
- Evaluate the feasibility and cost of involving the recreational angling community in pikeminnow removal through regulatory changes, a sport-reward program, or annual derbies.

5.1.2.4 Other suppression methods and strategies

- Systematically evaluate effectiveness of spearfishing for removing pikeminnow relative to other suppression methods.
- Evaluate feasibility of utilizing passive trapping techniques such a channel spanning fyke net or a weir leading to a trap to intercept or block pikeminnow during diel or seasonal movements. To inform this effort, use tagging studies, snorkel surveys (when clarity allows), or deployment of a stationary weir in the spring to improve understanding of winter and early spring distributing distribution and movement in the South Fork Eel River.
- Locate and target spawning or feeding aggregations of pikeminnow by tracking tagged fish or conducting snorkel surveys during the spring.
- Evaluate the feasibility of using a Trojan Y chromosome strategy for diminishing the reproductivity capacity of pikeminnow in the Eel River Basin (see Section 4.24).
- For all potential methods, describe and minimize adverse impacts to native fishes. If significant impacts are unavoidable, then the methods should be abandoned in favor of less impactful approaches.

5.1.3 Diet and impact on native species

Recommendations for improving understanding of pikeminnow diet and their impacts on native fishes in the Study Area are listed below. Refer to Section 4.3 for additional discussion of these recommendations.

- Collect pikeminnow diet samples in the summer in upper portions of the Study Reach where more juvenile steelhead are present to help assess pikeminnow predation impacts on steelhead.
- Collect pikeminnow diet samples during the winter and spring salmonid and lamprey outmigration period when pikeminnow are more likely to encounter juveniles of these species in high abundance. Coordinate with steelhead guides and anglers to help collect these samples.
- In addition to direct examination of gut contents, employ isotopic diet analysis of pikeminnow muscle tissue to describe relative contribution of major prey items to pikeminnow diet over a longer period (several weeks).
- Consider applying genetic analysis of gut contents (eDNA) to improve ability to detect target prey species in the diet of pikeminnow.
- Utilize bioenergetics modeling to help assess the magnitude of pikeminnow predation on native fishes in the Eel River. A bioenergetics model can be used to estimate the number of juvenile salmonids expected to be consumed by each pikeminnow size class based on seasonal diet composition, estimated pikeminnow population size, observed growth rates, and water temperature. Such a model could be used to (1) predict the number of pikeminnow that need to be removed to meaningful improve survival of native fishes of interest (2) develop removal targets, and (3) evaluate relative benefits of different management scenarios.
- Describe size-at-age and annual growth rates using scales from pikeminnow collected in the Study Area to support bioenergetics modeling and improve overall understanding of pikeminnow biology and population dynamics, including influence of density and other factors on pikeminnow growth rate.

5.1.4 Coordination and management planning

Ultimately, a large-scale, coordinated suppression program is needed to have meaningful longer-term impacts on the pikeminnow population in the Eel River basin. Key recommendations for developing such a program include:

- Improve coordination amongst Eel River stakeholders in studying and addressing the impacts of Sacramento Pikeminnow on native fish in the Eel River basin. Consider assembling an Eel River pikeminnow working group comprising state, federal, and tribal fisheries managers, conservation organizations, recreational and commercial fishing interests, and other stakeholders. This group would facilitate information sharing, collaboration, funding, and development and implementation of pikeminnow management strategies. The group could be organized under the existing Eel River Forum and would encourage regular informal email correspondence, as well as periodic pikeminnow management symposiums aimed at disseminating the latest research and management information on the species.
- Work closely with Eel River stakeholders to develop an adaptive Eel River Pikeminnow Management Plan that:

- o synthesizes information on Sacramento Pikeminnow life history, distribution, ecology, and population dynamics in the Eel River;
- o evaluates the population-level impacts of pikeminnow predation on native fish species in the Eel River based on diet studies and bioenergetics modeling;
- o describes the level-of-control and cost required to remove sufficient pikeminnow to result in a biologically meaningful increase in survival and production of native fishes; and
- o makes specific recommendations for implementing pikeminnow monitoring and population control in the Eel River Basin, including the best methods, locations, timing, life-stages, and considerations for monitoring program success and adaptive management.

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Appendices

Appendix A

South Fork Eel River Water Temperature Data

This appendix summarizes daily and annual statistics from continuous water temperature logger data collected at four sites in the South Fork Eel River between summer 2018 and winter 2019 (Tables A-1). Table A-2 and the subsequent figures include the following metrics:

- Daily mean, minimum, and maximum temperatures
- Maximum Daily Maximum Temperature (MDMT) for each year
- Maximum Weekly Maximum Temperature (MWMT), or the average of the daily maximum temperature during the warmest 7-day period in each year
- Maximum Weekly Average Temperature (MWAT), or the average of the daily mean temperature during the warmest 7-day period in each year.

Table A-1. Locations and deployment periods for water temperature loggers launched in the South Fork Eel River.

Logger description	Latitude (N)	Longitude (W)	River km	Deployment start	Deployment end	Notes
1.4 km downstream of Bull Cr	40.34796	-123.93121	1.7	7/5/2018	11/26/2019	Missing data from May 11–14, 2019
3.7 km downstream of Salmon Cr	40.25886	-123.84251	23.0	7/5/2018	11/26/2019	
3.0 km downstream of Dean Cr	40.16166	-123.79045	40.9	7/5/2018	11/26/2019	
Just upstream of Low Gap Creek	39.82388	-123.679297	117.3	6/23/2018	11/26/2019	

Table A-2. Annual water temperature statistics from data collected in the South Fork Eel River in 2018 and 2019.

Logger description	2018 statistics (°C)			2019 statistics (°C)		
	MDMT	MWMT	MWAT	MDMT	MWMT	MWAT
1.4 km downstream of Bull Cr	27.01	26.38	24.13	25.87	24.88	23.01
3.7 km downstream of Salmon Cr	28.62	27.67	24.66	26.57	25.81	23.74
3.0 km downstream of Dean Cr	29.79	28.88	26.05	27.75	27.19	24.52
Just upstream of Low Gap Creek	28.59	27.70	25.22	28.15	27.69	23.86

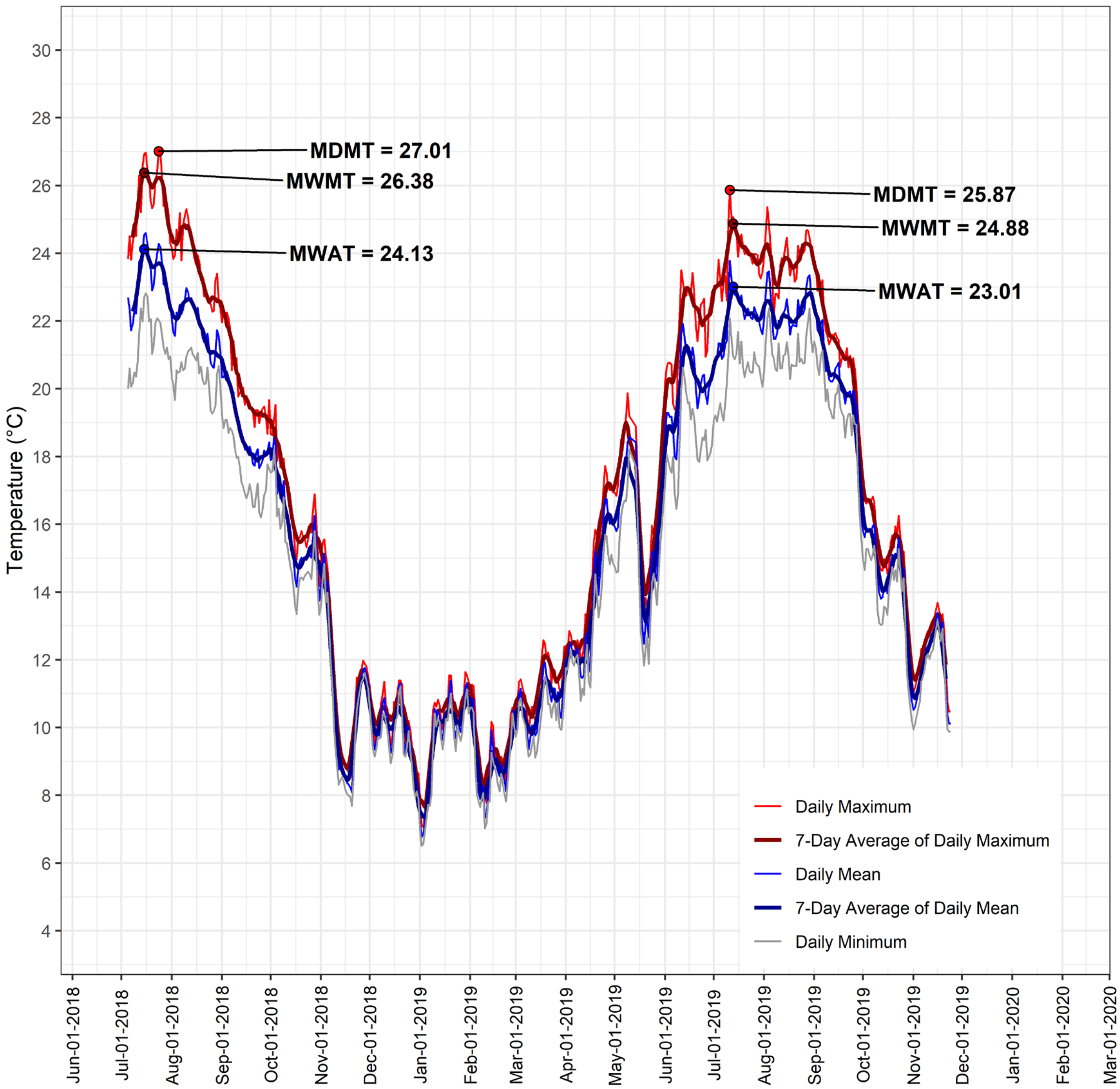

Figure A-1. Daily and annual water temperature statistics from continuous logger data collected in the South Fork Eel River downstream of Bull Creek from July 5, 2018 through November 26, 2019.

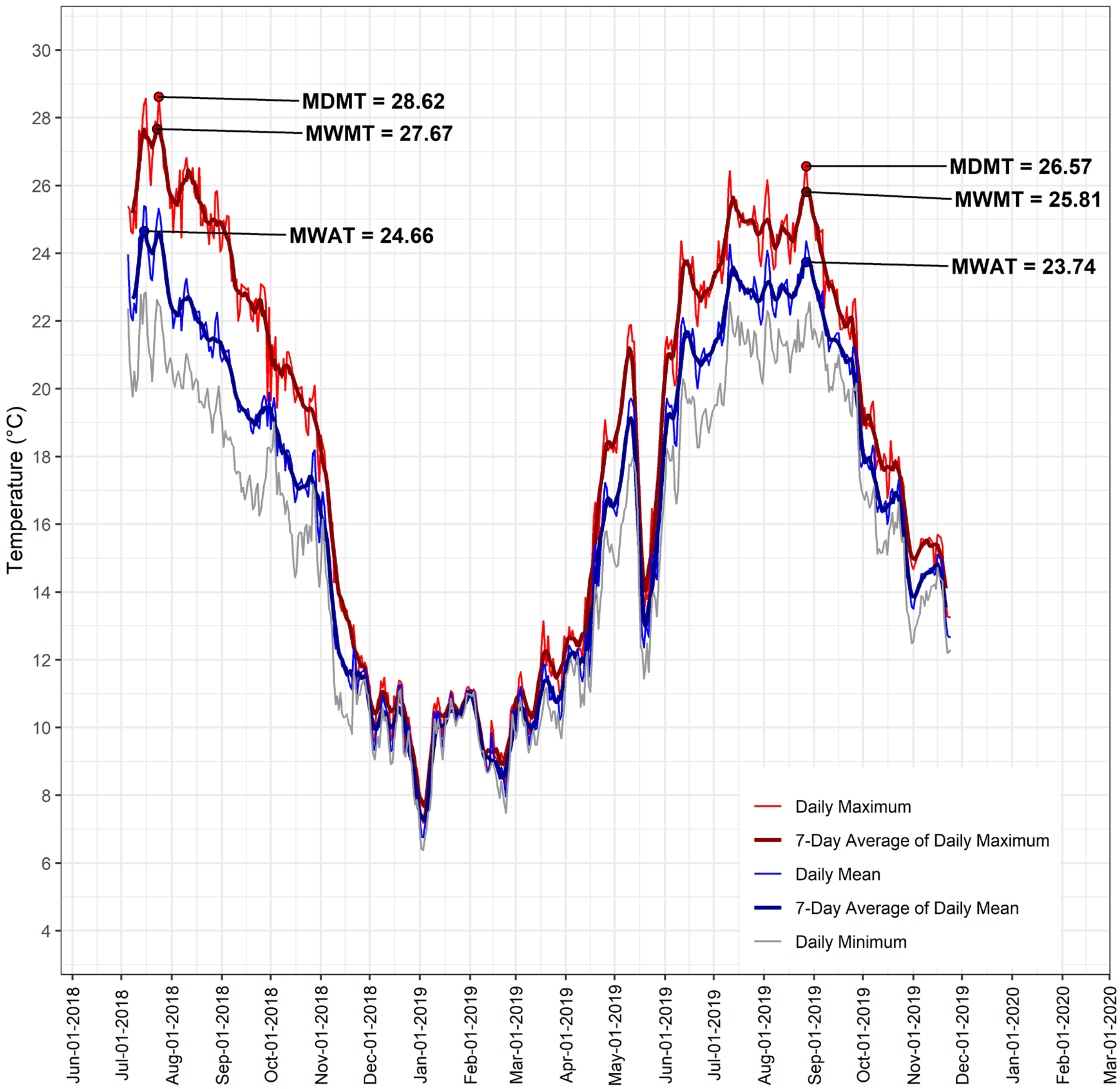

Figure A-2. Daily and annual water temperature statistics from logger data collected in the South Fork Eel River downstream of Salmon Creek from July 5, 2018 through November 26, 2019.

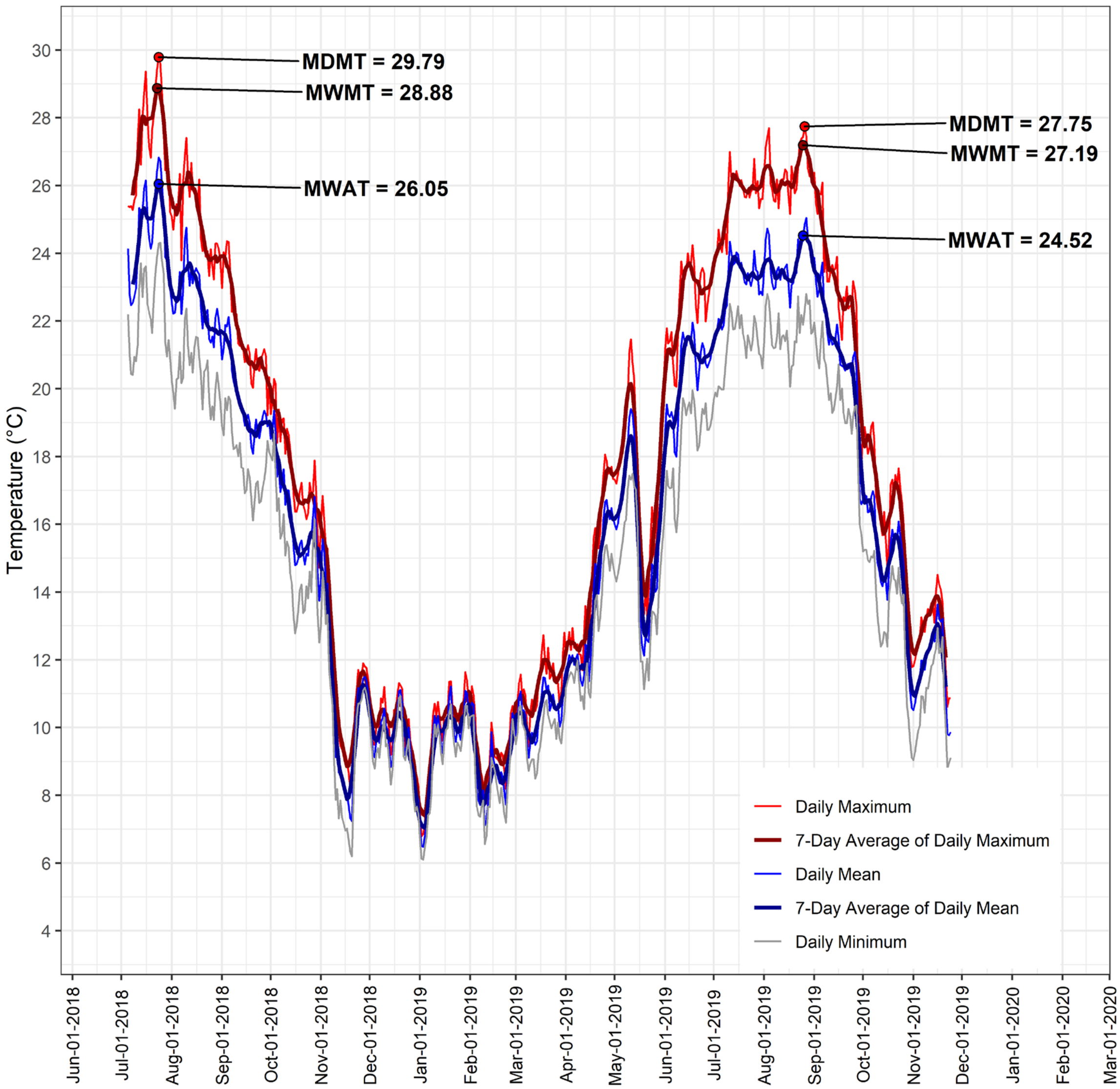

Figure A-3. Daily and annual water temperature statistics from logger data collected in the South Fork Eel River downstream of Dean Creek from July 5, 2018 through November 26, 2019.

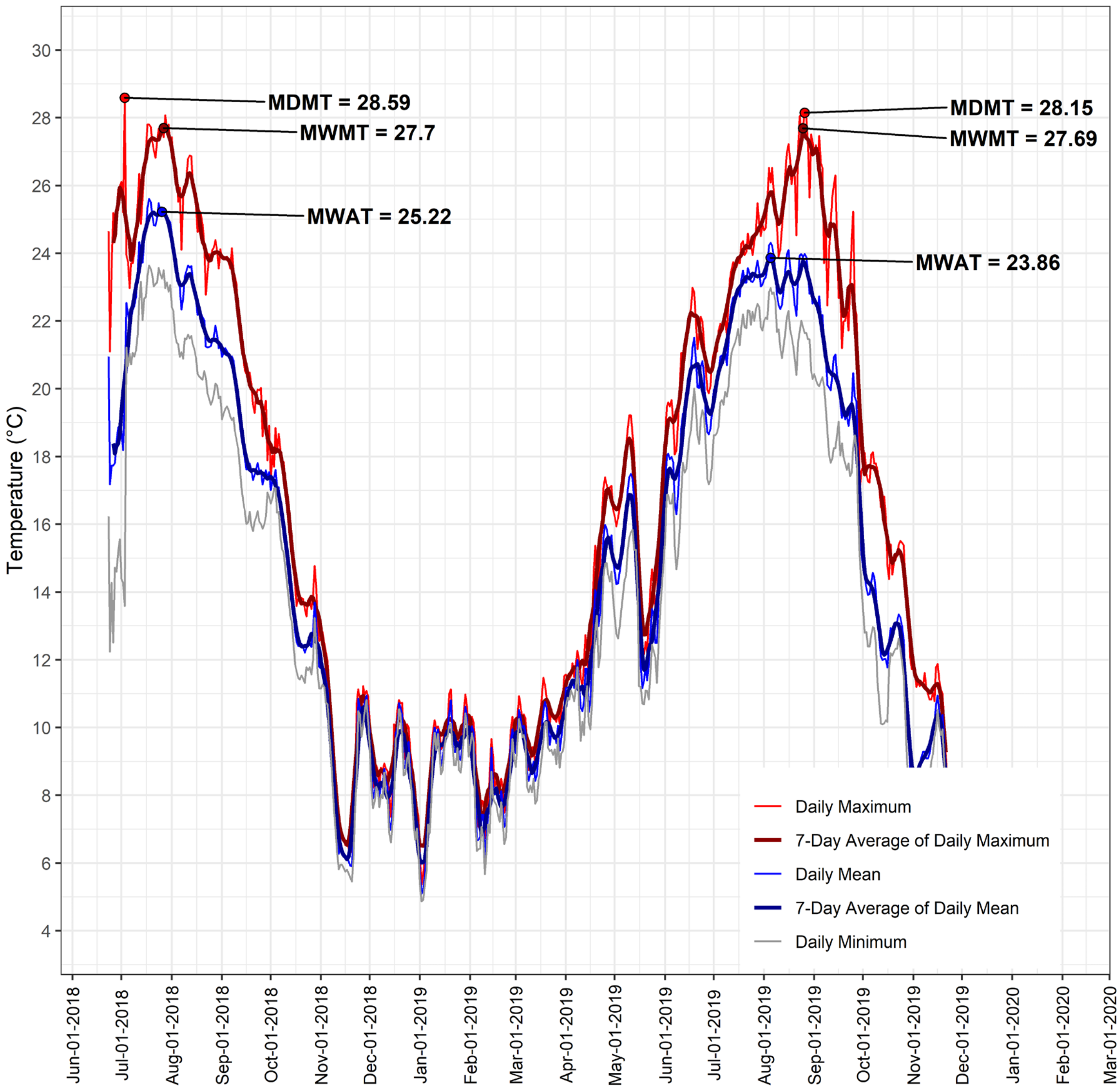

Figure A-4. Daily and annual water temperature statistics from logger data collected in the South Fork Eel River at Low Gap Creek from June 23, 2018 through November 26, 2019.

Appendix B

Sacramento Pikeminnow Weight Versus Length

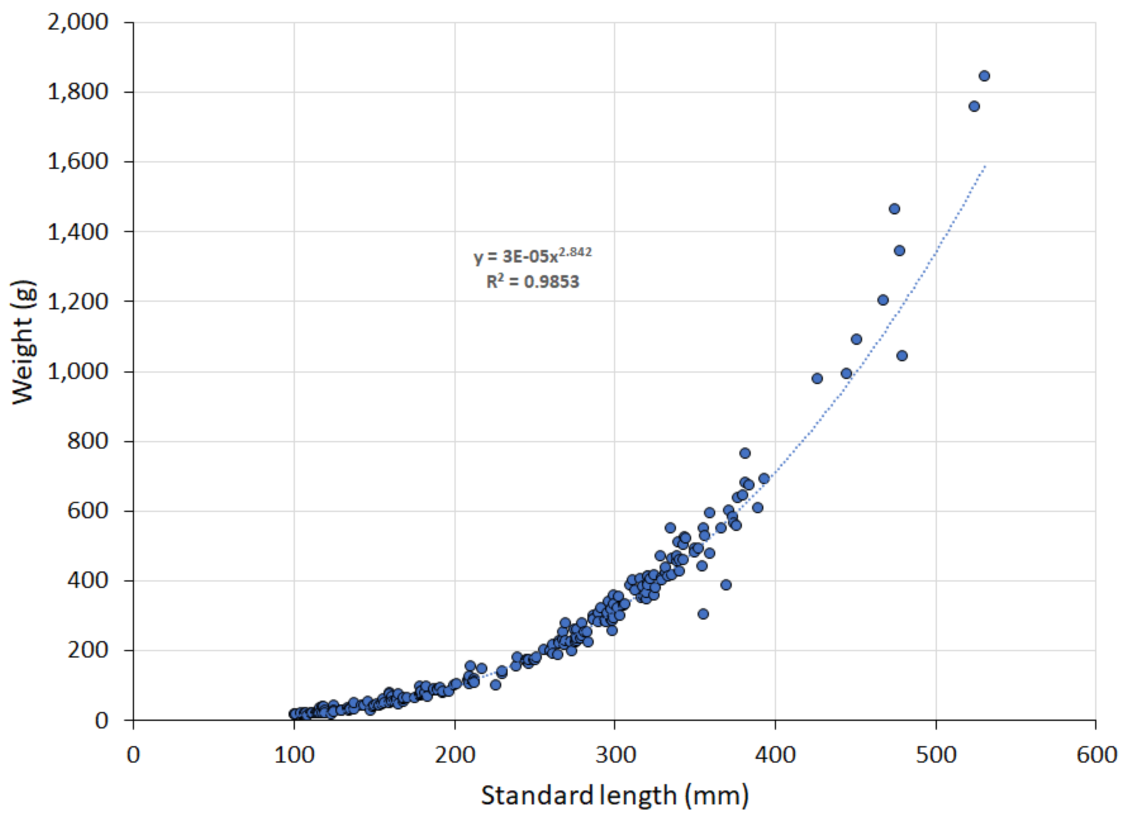

Figure B-1. Relationship between standard length and weight of Sacramento Pikeminnow captured during electrofishing trials in summer 2019.