

Evaluation of an effort to manage invasive Sacramento pikeminnow to support steelhead recovery in a small coastal watershed

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RESEARCH NOTE

Matt A. McKechnie^{1*}, Terra Dressler², Ethan Boucher Bell¹, Ken Jarrett¹, and Carolyn Geraghty³

¹ Stillwater Sciences, 1203 Main Street, Morro Bay, CA 93442, USA

 <https://orcid.org/0009-0005-0946-8886> (MAM)

² Stillwater Sciences, 996 S. Seaward Avenue, Suite 102, Ventura, CA 93001, USA

 <https://orcid.org/0000-0002-1794-4572>

³ Morro Bay National Estuary Program, 601 Embarcadero, Morro Bay, CA 93442, USA

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Sacramento pikeminnow (*Ptychocheilus grandis*; hereafter referred to as “pikeminnow”) are native to the Sacramento-San Joaquin, Russian, and Salinas Rivers in California, USA. Following their introduction to

Chorro Creek in the late 1970s, pikeminnow have established a persistent, self-sustaining population within this small coastal drainage that meets the ocean at Morro Bay, California. These invasive piscivores have deleterious effects on nearly all salmonid life stages through both direct (i.e., predation) and indirect (i.e., competitive exclusion) interactions which may be inhibiting the recovery of the native *Oncorhynchus mykiss* (steelhead/rainbow trout; herein referred to as *O. mykiss*) population (Brown and Moyle 1991; Brown and Moyle 1997; Brown and Brasher 1995; Nakamoto and Harvey 2003).

Chorro Creek is located on the California central coast of San Luis Obispo County ([Fig. 1](#)). The watershed drains 111 km² and is unique among central California coast watersheds in that it is largely undeveloped, has perennial flows, and provides near year-round connectivity to a highly productive estuary, Morro Bay. Chorro Creek supports federally threatened *O. mykiss* belonging to the South-Central California Coast Distinct Population Segment. Snorkel surveys conducted in Chorro Creek in the early 2000s found no young-of-year (YOY) *O. mykiss* and low numbers of juvenile *O. mykiss*. The most abundant fish observed during the TRPA (2001) study was pikeminnow, and the absence of YOY *O. mykiss* was attributed to potential predation by pikeminnow. Pikeminnow suppression efforts were initiated in Chorro Reservoir in 2006 to address the source population and later expanded in 2008 to include Chorro Creek from the tidal extent upstream to Chorro Reservoir (Halligan and Otte 2011). Suppression efforts in Chorro Creek occurred annually from 2008–2010 and resulted in the reduction of adult pikeminnow; however, *O. mykiss* abundance was not monitored during these suppression efforts.

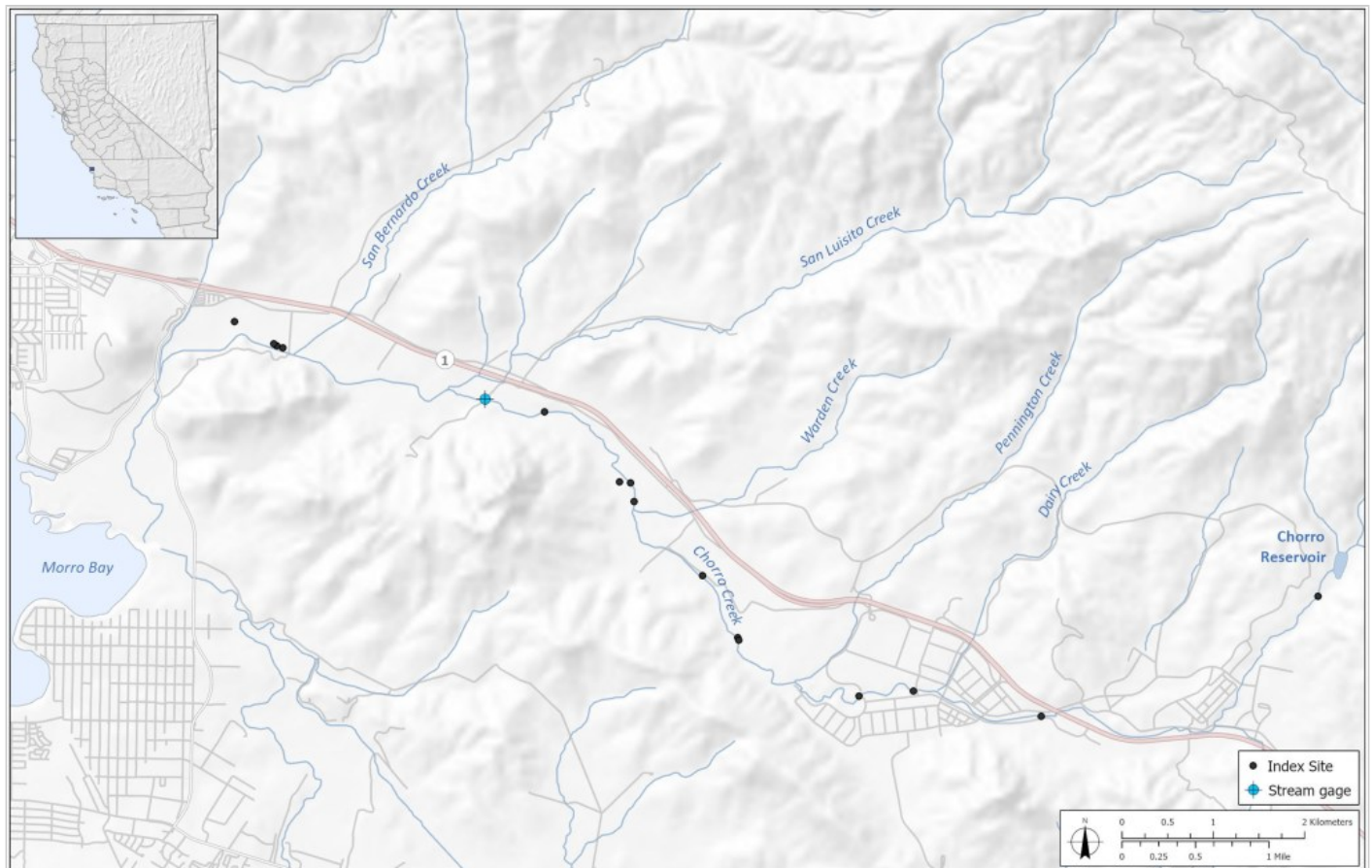


Figure 1. Study Area and index sites within Chorro Creek, San Luis Obispo County, CA, USA.

Within Chorro Creek, pikeminnow predation on *O. mykiss* has been confirmed through environmental

DNA (eDNA) analysis of pikeminnow gut contents (Jarrett et al. 2019). In this study, *O. mykiss* DNA was detected within the gut contents of 18% of the sampled pikeminnow, indicating a substantial level of predation within the watershed. Consequently, the pikeminnow population represents a threat to the recovery of *O. mykiss* within Chorro Creek (NMFS 2013).

To address management objectives in the South-Central California Coast Steelhead Recovery Plan (NMFS 2013), and to aid in the recovery of the *O. mykiss* population, a Pikeminnow Management Plan was developed and implemented in 2017 (Stillwater Sciences 2017). Pikeminnow “management,” or “suppression,” is defined as the effort to remove pikeminnow from the watershed, such that their effect on native fishes is dampened. In this study, we evaluate whether a modestly funded pikeminnow management program can be effective at increasing *O. mykiss* abundance in the watershed.

We used a variety of control methods to suppress the pikeminnow population in Chorro Creek, including single-pass and multiple-pass backpack electrofishing, angling, and beach seining. Suppression efforts were conducted during the fall (late September–early November), when stream flows are at their lowest and pikeminnow are concentrated into smaller areas. The majority of the habitat in Chorro Creek during this time of the year is less than 1.2 m in depth, which facilitates efficient conditions for backpack electrofishing. To evaluate the efficacy of suppression efforts at limiting the pikeminnow population, and to assess annual trends in the abundance of *O. mykiss* and pikeminnow, we established multiple-pass depletion backpack electrofishing sites (i.e., index sites) throughout mainstem Chorro Creek within habitat units that contained suitable habitat for both species and had documented presence of pikeminnow (Stillwater Sciences 2017). Multiple-pass backpack electrofishing was conducted following methods by Pollock and Otto (1983) and the National Marine Fisheries Service (NMFS 2000) guidelines for electrofishing waters containing salmonids listed under the Endangered Species Act. Field activities were conducted under a California Department of Fish and Wildlife scientific collection permit (S-190250002-20023-001) and a National Marine Fisheries Service 10(a)1(A) permit (20085-3A). All captured *O. mykiss* and pikeminnow were measured to standard length (SL) and fork length (FL). Pikeminnow were humanely euthanized following methods included in the American Veterinary Medical Association (AVMA 2013) guidelines, and all other fish were returned to the stream after measuring.

The level of effort applied to pikeminnow suppression each year was constrained by available funding. EPA funds provided by the Morro Bay National Estuary Program and California Department of Fish and Wildlife Proposition 1 funding were matched with equipment donations from Stillwater Sciences. Field crews were staffed with Stillwater Sciences biologists as well as volunteers from the Watershed Stewards Program, California Conservation Corps, and community members. With an average field implementation budget of \$22,000 per year, pikeminnow suppression efforts were implemented for an average of 10.5 days per year beginning in 2017. We were able to sample an average of 10 index sites per year, as well as conduct a variety of other control measures including single-pass backpack electrofishing, angling, and beach seining, capturing a total of 2,670 pikeminnow throughout mainstem Chorro Creek ([Table 1](#)).

Table 1. Level of effort and number of pikeminnow captured across each suppression year.

Year	Field Implementation Budget	Number of Suppression Days	Linear Distance Sampled (m)	Pikeminnow Captured
2017	\$7,200	6	347	224

Year	Field Implementation Budget	Number of Suppression Days	Linear Distance Sampled (m)	Pikeminnow Captured
2018	\$4,690	11	184	88
2019	\$8,000	9	1,128	218
2020	\$21,030	10	2,114	117
2021	\$37,818	12	3,427	191
2022	\$37,818	12	3,668	209
2023	\$37,818	14	3,610	1,027
2024	\$20,900	10	2,808	596
Total	\$175,274	84	17,286	2,670

Analyses were based on results from index sites that were sampled over multiple years and were conducted in R version 4.2.2 with a significance level of $\alpha = 0.05$ for statistical tests. Abundance was estimated within index sites for each multiple-pass sampling event using depletion curves generated using the ‘FSA’ package (Ogle et al. 2025). Due to substantial variability in the size of index sites, fish densities were calculated by normalizing abundance estimates to unit length. Density (estimated abundance/100 m) was used as the dependent variable in models.

We used regression models to evaluate the density of pikeminnow and *O. mykiss* at index sites over time and to test for an overall relationship between pikeminnow density and *O. mykiss* density. Because the response variables consisted of count data with many zeros, we evaluated several candidate model structures. Model types testing *O. mykiss* density over time included linear regression and linear mixed effects models with a site identifier as a random effect (R package: lme4; Bates et al. 2015). Pikeminnow data trends indicated potential exponential relationships, so fish density and the natural log of fish density, $\ln(\text{density})$, were both tested as dependent variables to compare the fit of linear vs exponential curves. These models were also tested against negative binomial regression, and zero-inflated negative binomial regression models (R package: glmmTMB; Brooks et al. 2017). Akaike information criterion (AIC) was used to select the best fit of all significant models. Pikeminnow are gape limited, and larger and older individuals are more piscivorous than younger and smaller individuals. Based on the results of the gut content analysis in Jarrett et al. (2019) and visual gut content observations in this study, pikeminnow in the Chorro Creek watershed are assumed to become piscivorous at age 1+; equivalent to 70 mm SL or larger. Therefore, in this study age 1+ and older pikeminnow (>70 mm SL; herein referred to as “large” pikeminnow) were assessed separately from YOY pikeminnow (≤ 70 mm SL). Index sites where pikeminnow were never captured were excluded from this analysis.

Rainfall corresponding to each sample year was also tested within these models as an additional fixed effect to assess the potential influence of environmental conditions on pikeminnow densities. Rainfall data was sourced from a San Luis Obispo County stream gage located in the watershed (Canet station 747; [Fig. 1](#)), and rainfall accumulation (cm) was calculated for the water year (starting 1 October) immediately preceding each suppression event. Rainfall accumulation varied between years, ranging from 29.5–80.9 cm ([Table 2](#)).

Table 2. Annual rainfall (cm) according to the San Luis Obispo County stream gage (Canet station 747) in San Luis Obispo County, CA, USA, for the water years (1 October–30 September) immediately preceding each suppression event.

Year	Annual rainfall (cm)
2017	65.3
2018	33.5
2019	50.7
2020	31.1
2021	29.5
2022	31.6
2023	80.9
2024	53.2
Average Annual Rainfall	47.0

Data from suppression efforts over the 2017 to 2024 period show that YOY *O. mykiss* (<120 mm FL) density did not exhibit an overall relationship with year (linear mixed effects model; $\chi^2 = 0.52$, df = 1, P = 0.473). However, pairwise comparison between years revealed that YOY *O. mykiss* density increased significantly after the initiation of suppression efforts in year 1, 2017, and remained elevated between years 2–6 before declining again in year 7, 2023 (linear mixed effects model; $\chi^2 = 21.21$, df = 7, P = 0.003; [Fig. 2](#)). Importantly, 2023 and 2017 had the highest annual rainfall of all suppression years ([Table 2](#)). YOY *O. mykiss* emerge from spawning gravels in the spring (NMFS 2013), following the period of time when the majority of rainfall occurs in this system ([Fig. 3](#)). It is possible that high flows during 2017 and 2023 caused emerging *O. mykiss* to become displaced downstream, contributing to lower YOY *O. mykiss* densities in index sites later in the year. Density of age 1+ *O. mykiss* (≥ 120 mm) did not differ between years (linear mixed effects model; $\chi^2 = 10.55$, df = 7, P = 0.159; [Fig. 2](#)).

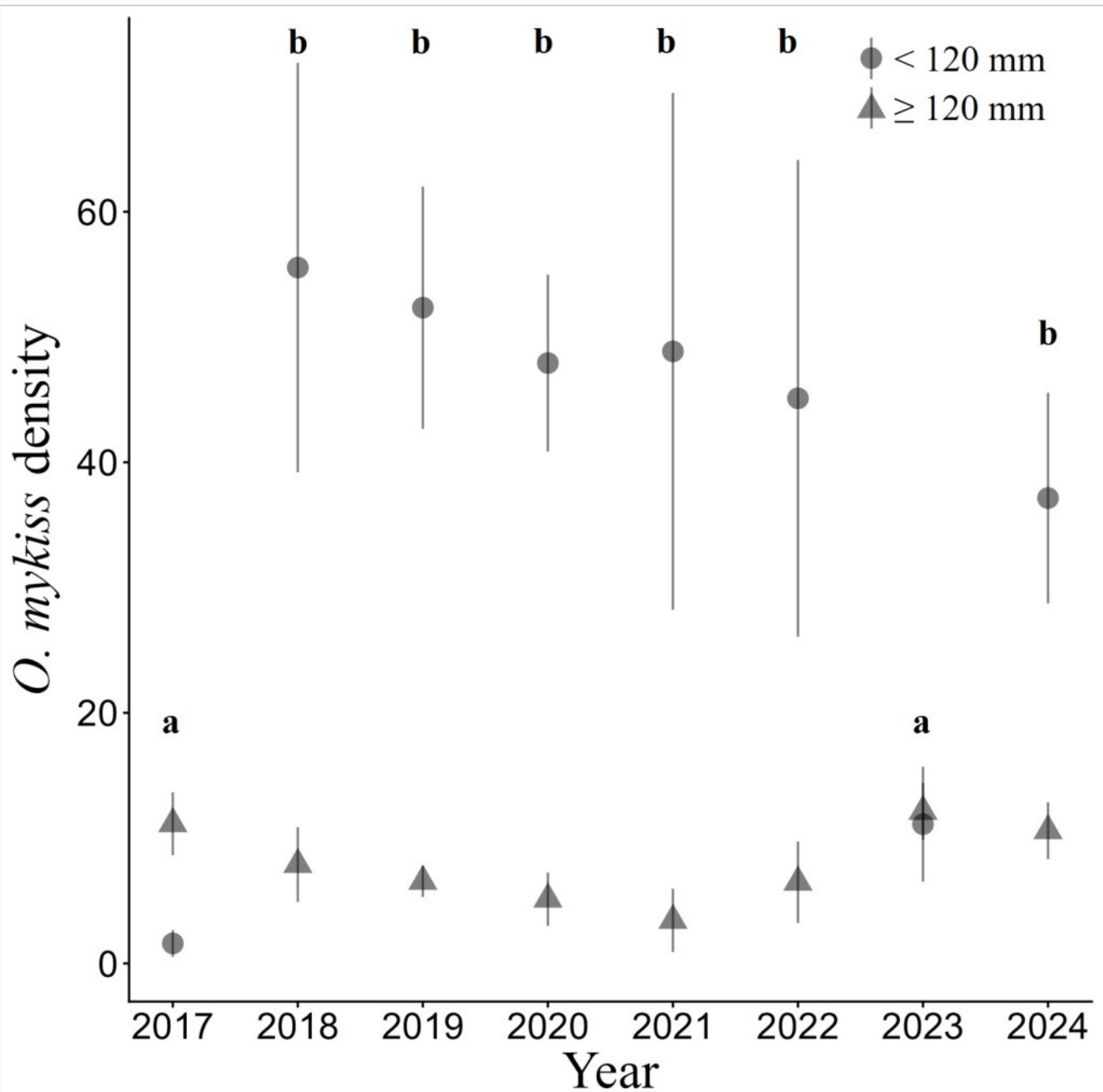
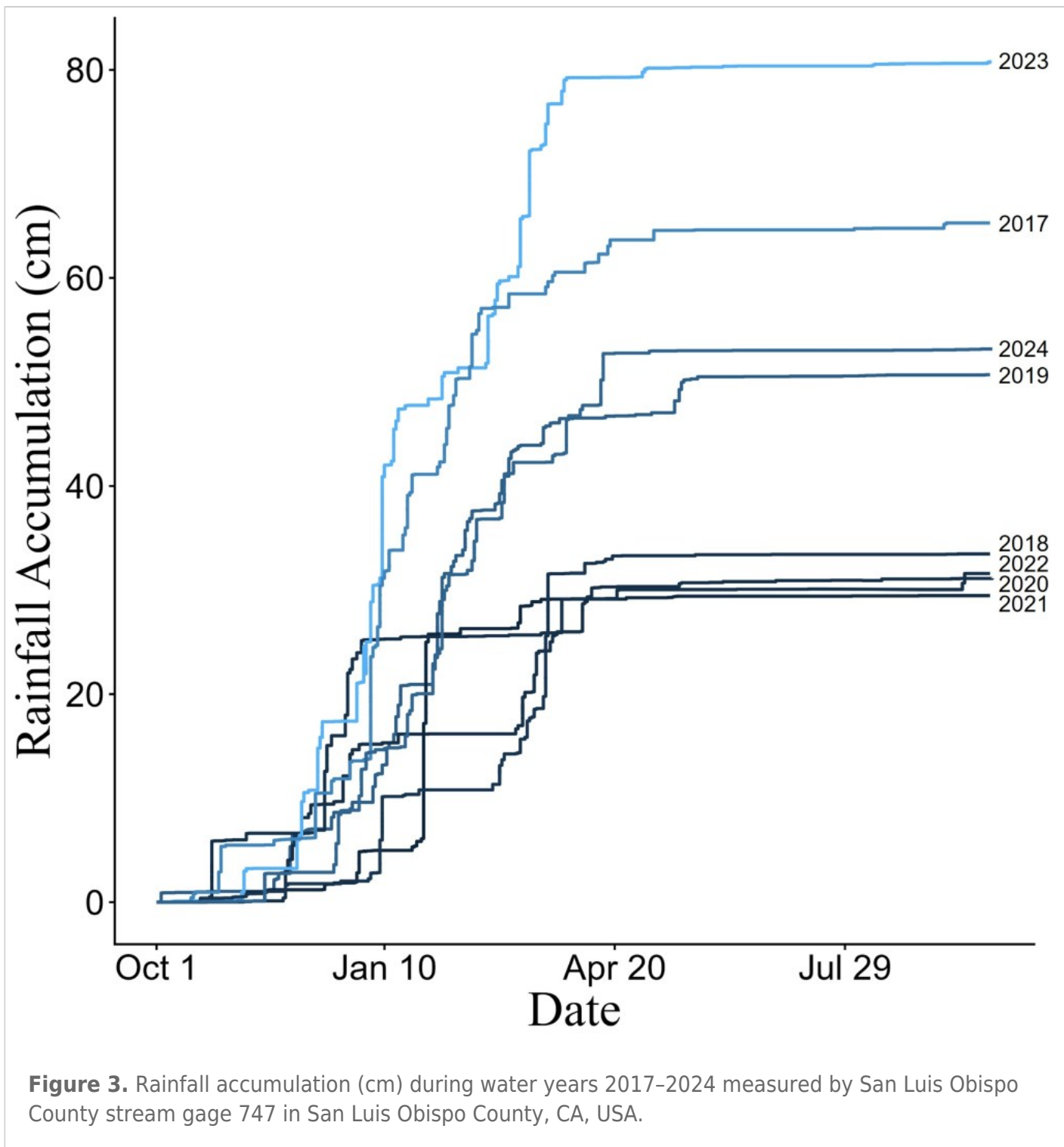


Figure 2. Estimated density (mean $\pm$ SEM number of fish per 100 m) of *O. mykiss* (young-of-year and age 1+ or older) at index sites in Chorro Creek, San Luis Obispo County, CA, USA, from 2017-2024.



YOY pikeminnow density exhibited a significant exponential decline over time (linear mixed effects model; $\chi^2 = 30.8$, $df = 1$, $P < 0.001$) while rainfall had a significant positive effect on YOY pikeminnow density ($\chi^2 = 58.4$, $df = 1$, $P < 0.001$), so both of these variables were included in the final model ([Fig. 4](#)). Large pikeminnow density did not appear to change over time when density was compared between calendar years (i.e., 2017, 2018, etc.). Because larger individuals are rarer than YOY and less likely to inhabit pools that meet depth requirements for effective electrofishing depletion, the initial sampling design was likely insufficient for detecting change in large pikeminnow density. In fact, only 2 of the index sites originally sampled in 2017 contained large pikeminnow. Therefore, additional index sites were

added as the project progressed, including sites located closer to the source population ([Fig. 1](#)). When large pikeminnow density was modeled against suppression year (i.e., the number of years suppression has taken place at a given index site) rather than calendar year, density displayed a modest but significant exponential decline over time (linear regression; $F = 4.82$, $df = 1$, $R^2 = 0.09$, $p = 0.033$; [Fig. 5](#)). Rainfall was not found to have a significant effect on large pikeminnow density, and its inclusion did not improve model fit, so it ultimately was dropped from the final model.

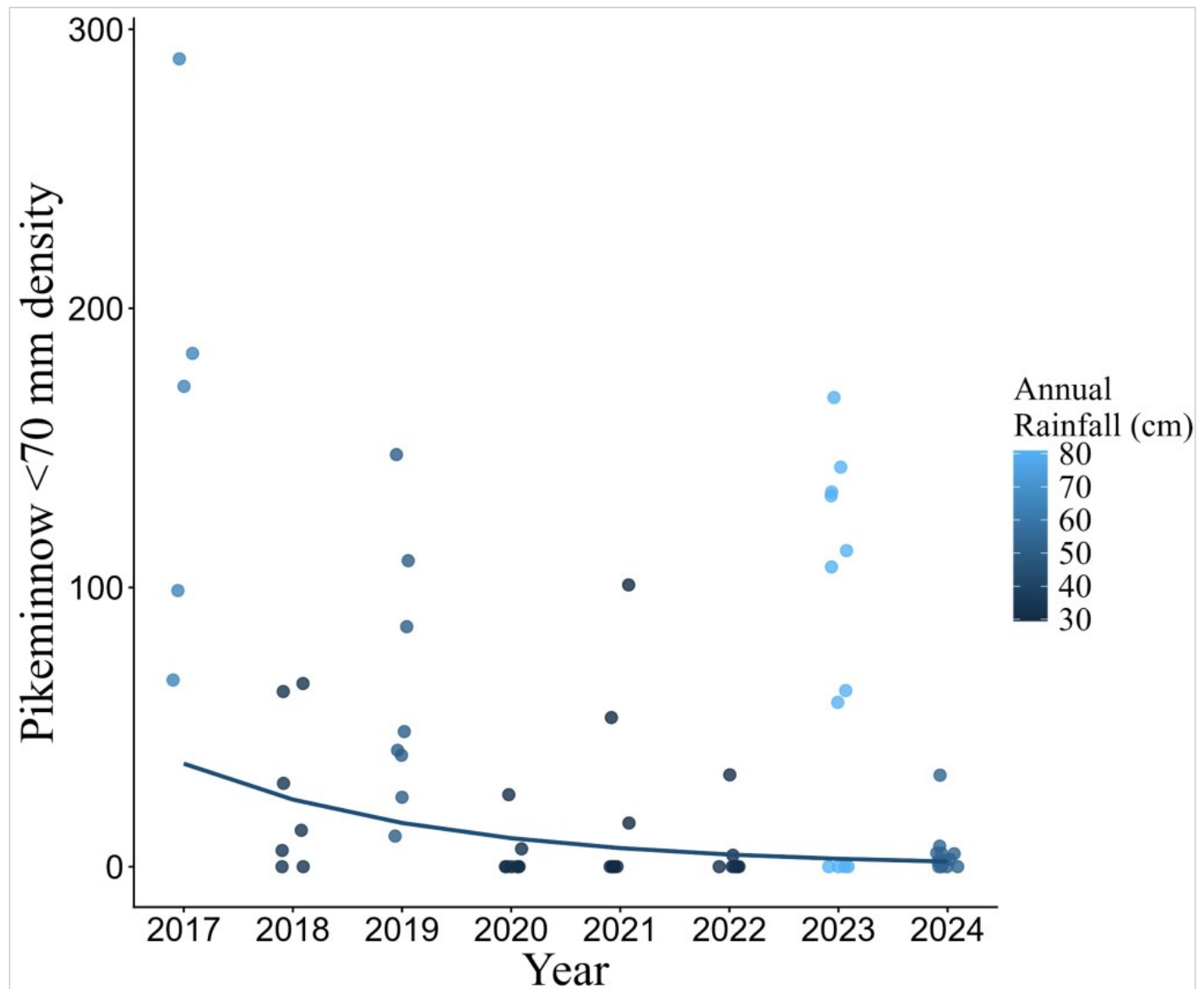


Figure 4. Estimated density (number of fish/100 m) of young-of-year (≤ 70 mm standard length) pikeminnow at index sites in Chorro Creek, San Luis Obispo County, CA, USA, from 2017–2024. Color shading indicates relative annual rainfall (cm) during the water year immediately preceding each suppression event. The fitted curve represents the best fit relationship between sample year and YOY pikeminnow density at the average rainfall (47 cm) across all study years.

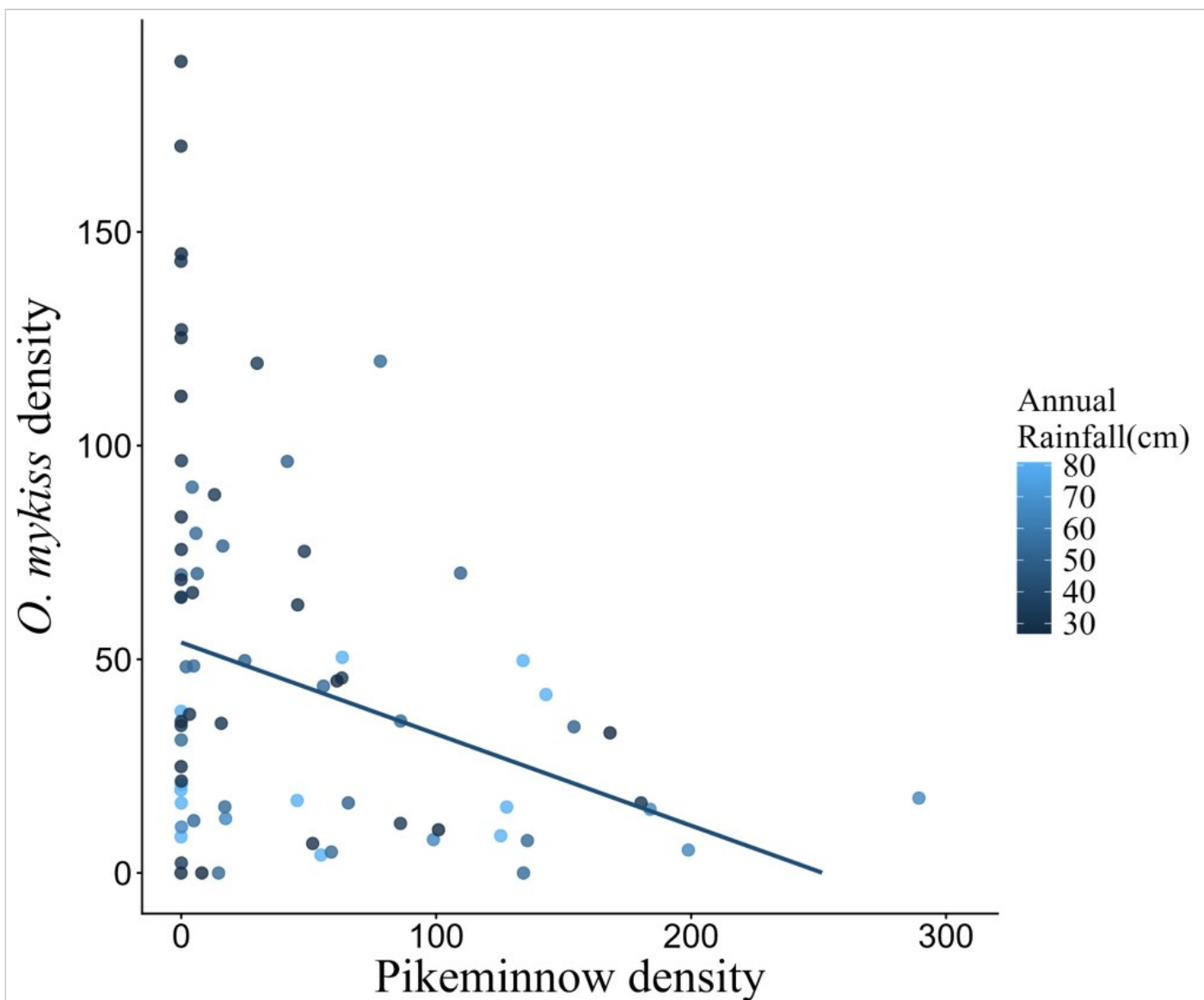


Figure 6. Estimated density (number of fish per 100 m) of *O. mykiss* versus estimated density of pikeminnow for each sampling event at each index site in Chorro Creek, San Luis Obispo County, CA, USA, from 2017–2024. The fitted line displays the best fit relationship between *O. mykiss* and pikeminnow density at the average rainfall (47 cm) across all study years.

Results of this study show an overall decline in pikeminnow density within index sites sampled over the duration of the suppression program despite annual recruitment of pikeminnow in the watershed (indicated by occurrence of YOY in all years; Stillwater Sciences 2024). Data suggests *O. mykiss* densities respond positively within index sites following the initiation of suppression efforts and decreases in large pikeminnow following suppression efforts appear to be contributing to more favorable conditions for native *O. mykiss*. Suppression efforts have been effective at reducing the population of large pikeminnow within index sites, presumably reducing predation pressure on juvenile *O. mykiss*. However, YOY pikeminnow continue to influence rearing conditions for *O. mykiss* through competitive interactions, particularly following years with high rainfall.

Limitations of this study design include the relatively small number of index sites containing large pikeminnow and the potential for habitat at index sites to shift over time (e.g., from sediment movement during storms) in ways that could influence fish density irrespective of suppression efforts. Future efforts that aim to quantify the impact of suppression efforts should establish more index sites that are likely to contain large pikeminnow to increase sample size as well as “control” sites at locations where the target invasive species is not present. We also recommend collection of additional habitat metrics within index sites over time such as channel width, depth, cover types and continuous temperature to assess how habitat variables may influence study outcomes.

The results of this study suggest that suppression efforts at the current scale have conferred benefits to the *O. mykiss* population in Chorro Creek. While complete eradication of the pikeminnow population will likely require additional approaches and effort, the current suppression program has been aiding in the recovery and resiliency of the native *O. mykiss* population and is relatively low cost when compared to other suppression programs. Our research indicates that if there is another hiatus in pikeminnow suppression efforts in Chorro Creek, similar to the gap in suppression from 2010–2017, we can expect a substantial resurgence in the pikeminnow population, as evidenced by the high numbers of large pikeminnow captured in 2017 (Halligan and Otte 2011; Stillwater Sciences 2017) and by the response of YOY pikeminnow to high rainfall in spite of suppression efforts in the present study.

Recent efforts to evaluate the feasibility of implementing a Trojan Y Chromosome strategy (TYC) on pikeminnow in the Eel River in northern California, indicate this method holds potential for long-term success, although additional research is needed before field implementation (Juan and Bucheister 2025). The most viable path towards full eradication will likely require a combination of manual suppression efforts and the implementation of a TYC, as described by Lyu et al. (2020) and Juan and Bucheister (2025). In modeled simulation runs of TYC coupled with manual suppression, Juan and Bucheister (2025) found the predicted extirpation rate greatly increased when manual suppression efforts were implemented simultaneously. We are actively monitoring the progress of Eel River TYC program and remain optimistic that our ongoing control efforts in Chorro Creek will enhance the feasibility and effectiveness of a similar strategy in this watershed. Until a path toward TYC is identified, our goal is to continue to suppress the pikeminnow population annually within Chorro Creek.

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