San Joaquin River Restoration Program: Fish Assemblage Inventory and Monitoring, 2012–2013

SAN JOAQUIN RIVER
RESTORATION PROGRAM

February 2014

ACRONYMS AND ABBREVIATIONS

CFS	cubic feet per second
CPUE	catch-per-unit-effort
mg/L	milligrams per liter
NTU	nephelometric turbidity units
SJR	San Joaquin River

Symbols

°C	degrees Celsius
µS/cm	microsiemens per centimeter

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INTRODUCTION

In 1988, a coalition of environmental groups, led by the Natural Resources Defense Council (NRDC), filed a lawsuit challenging the renewal of long-term water service contracts between the United States and the Central Valley Project Friant Division Long-Term Contractors. After more than 18 years of litigation of this lawsuit, known as NRDC *et al.* vs. Rodgers *et al*., 2006, a settlement was reached. The stipulation of the Settlement establishes two primary goals: (1) Restoration – to restore and maintain fish populations in "good condition" in the mainstem San Joaquin River (SJR) below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish and (2) Water Management – to reduce or avoid adverse water supply impacts on all of the Friant Division long-term contractors that may result from the Interim and Restoration Flows provided for in the Settlement.

Historically, the river supported fall- and spring-run Chinook salmon (*Oncorhynchus tshawytscha*) and other native fishes, but salmon runs in the SJR were extirpated above the Merced River confluence by the late-1940s (Yoshiyama *et al.* 2002). The SJR drainage supported "an excellent spring run and a small fall run (Fry 1961)." Spring run Chinook salmon would migrate during high spring flows fed by Sierra Nevada snow-melt and hold in higher elevation streams until fall spawning (Fry 1961). A series of bypass systems such as dams, bifurcation structures, levees and flood channels have led to the loss of fish migration access, fish habitat, species diversity and altered environmental factors. The flow regimes in this highly managed system are regulated by various federal and state agencies which divert SJR water for irrigation, leaving the main channel dry for miles in some reaches. The largest diversion from Friant Dam is the 151.8 mile Friant-Kern Canal with a capacity of 5,000 cubic feet per second (cfs) until reaching the Kern River at 2,000 cfs (Friant Dam Project). The canal supplies irrigation water to Fresno, Tulare, and Kern counties.

This study is designed to assess achievement of the Restoration Goal over time, by developing baseline fish population information throughout the Restoration Area, and supporting a long-term monitoring program to detect changes in fish populations as the Restoration Program (Program) proceeds. Information on the temporal and spatial distribution, species occurrence, and will help the Program assess progress towards Restoration Goal. This information can also be used to inform adaptive management decisions for the Program.

The response of Chinook salmon and other fishes to current habitat conditions (*e.g.*, temperature, streamflow) is unknown. A number of issues must be addressed due to historic alterations to the SJR (*e.g.*, river connectivity, passage, water quality) to re-establish native fish populations. The Fisheries Management Plan for the Program states that approximately 21 native fish species historically inhabited the San Joaquin River, however, at least eight of these species are now uncommon, rare, or extinct (SJRRP 2010).

Fishery and aquatic resource assessments were conducted by the California Department of Fish and Game (DFG, now California Department of Fish and Wildlife) from 2003 – 2005 as the first step in pre-restoration monitoring (DFG 2007). Standardized sampling protocols, including increased sampling effort, have been developed to help the Program assess changes in fish populations throughout the restoration process. Standardized time-series data are critical for assessing management actions because fish populations may take several years to respond (Bonar *et al.* 2009). A variety of gear types are required to maximize capture efficiency and to sample the entire assemblage of fishes in a non-wadeable stream like the SJR (Curry and Munkittrick 2005; Lavigne *et al.* 2008; Guy *et al.* 2009). Some gear types for river sampling include boat and backpack electrofishing, seining, trammel netting, gill netting, trawling, and snorkeling. Standardized river sampling is often conducted on a reach scale, with reaches established to represent specific fish and habitat characteristics (Curry *et al.* 2009). The reaches of the SJR, as delineated in Chapter 2 of the Fisheries Management Plan (SJRRP 2010) provide the boundaries for standardized sampling protocols within each reach.

METHODS

The long-term goal of Inventory and Monitoring (I&M) efforts is to develop baseline fish assemblage data throughout the Restoration Area. As habitats are improved to meet the Restoration Goal, ongoing monitoring can be used to evaluate changes in the fish community and better inform management decisions regarding the restoration process. Current objectives include: provide baseline data of fish assemblages present during quarterly field sampling, and to establish protocols for subsequent I&M efforts. Specific elements of physical and biological assessments within the Restoration Area will be used to evaluate the long-term efforts of the Restoration Program relating to fish assemblage structure and change over time.

Site Description

The Restoration Area extends from Friant Dam to the confluence of the San Joaquin and Merced rivers. This area is approximately 150 miles long. The Restoration Area is further divided into five main reaches, delineated by the Fisheries Management Work Group, largely defined by existing structures on or near the river (figure 1; SJRRP 2010).

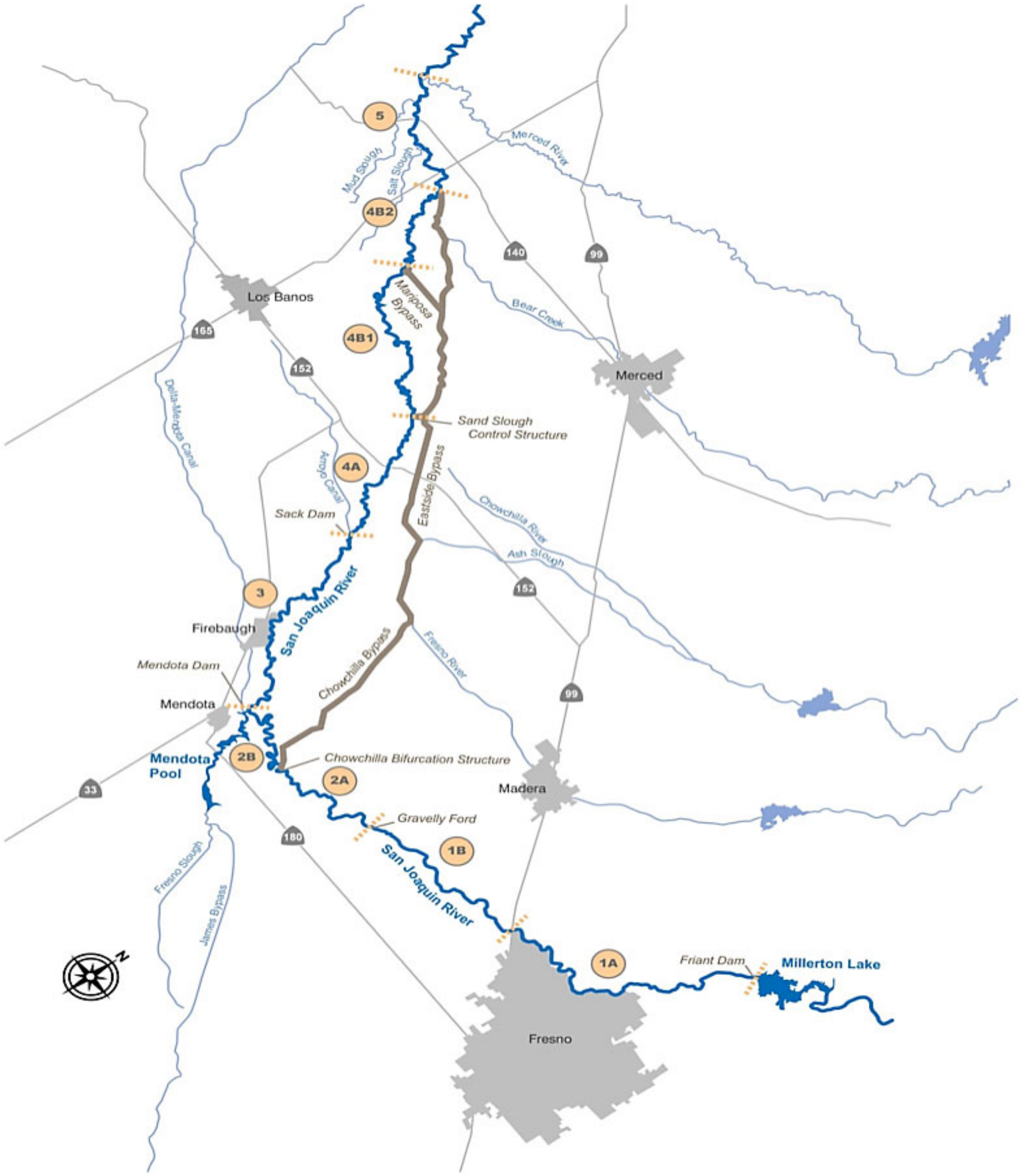


Figure 1.—Map of the San Joaquin River Restoration Area and associated Reaches. The area encompasses the San Joaquin River below Friant Dam to the confluence of the Merced River. The yellow circles identify the associated restoration reach, and the dashed line identifies the boundary between reaches.

Reach 1 (figures 2 – 3): Friant Dam (~ RM 267.5) to Gravelly Ford (~ RM 228.9), subdivided into Reach 1A: Friant Dam to State Route (SR) 99 (~RM 243.1) and, Reach 1B: SR 99 – Gravelly Ford. In general, Reach 1A is characterized by a single channel, with cobble or bedrock substrate, perennial flow, with low conductivity, clear water flowing out of Millerton Lake. Major structures in this reach include rock weirs within Lost Lake Recreation Area (Fresno County), and several areas downstream where in-river or side channel habitat are affected by current or past mining operations. In Reach 1B, substrate

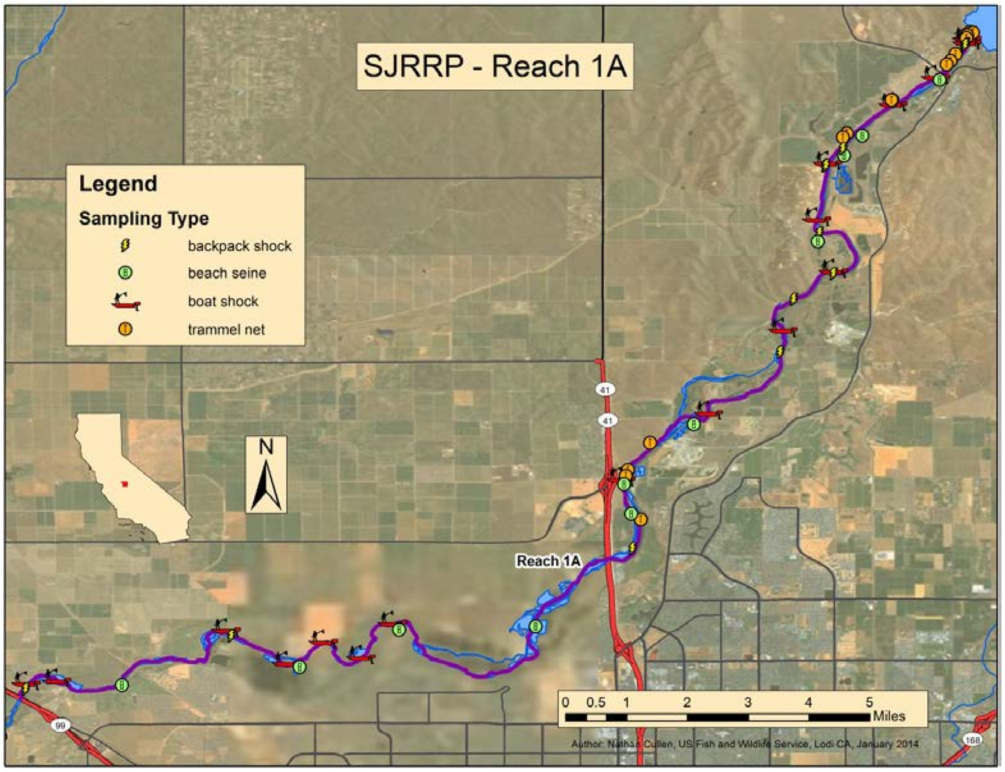


Figure 2.—Map of Reach 1A and associated sampling sites.

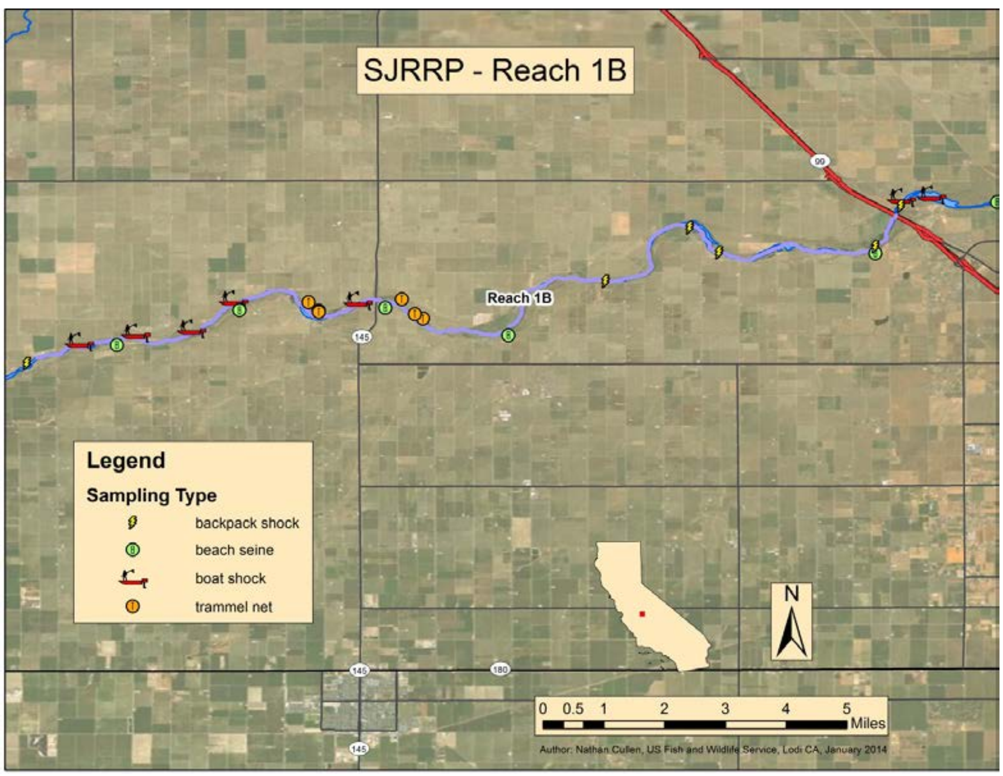


Figure 3.—Map of Reach 1B and associated sampling sites.

changes from cobble and bedrock to sand. Like downstream stretches of Reach 1A, Reach 1B also contains in-river of side channel habitat affected by mining operations (b/w RM 234 and RM 232). Reach 1B is generally a single channel, though large, deep bodies of water are present where abandoned in-river mine pits exist.

Reach 2 (figure 4): Gravelly Ford (~ RM 228.9) to Mendota Dam (~ RM 204.7), subdivided into Reach 2A: Gravelly Ford to the Chowchilla bifurcation structure (~ RM 216) and Reach 2B: Chowchilla bifurcation structure to Mendota Dam. Reach 2 is generally a wide, shallow, braided channel with sandy substrate. Primary structures in Reach 2 include Chowchilla Bifurcation Structure, San Mateo Crossing, and Mendota Pool. Several water inputs and withdrawals are present in Mendota Pool, including Fresno Slough and the Delta-Mendota Canal. Towards Mendota Pool, riverbed material shifts from sand to mud, and aquatic vegetation (*e.g., Typha*) is more abundant.

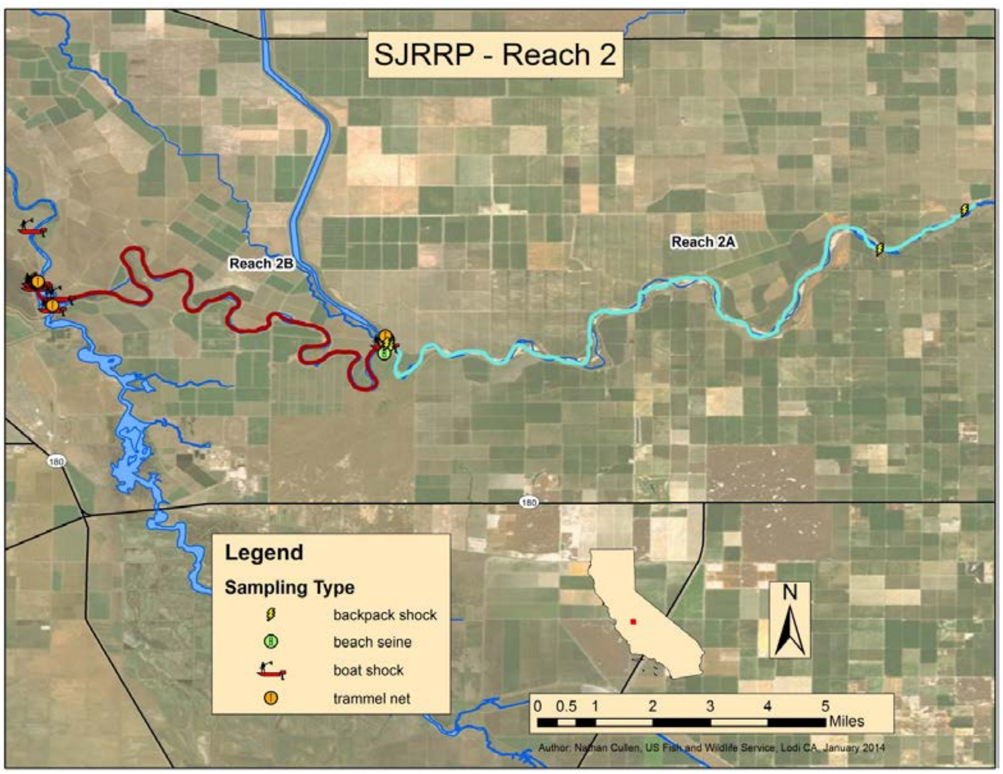


Figure 4.—Map of Reach 2 and associated sampling sites.

Reach 3 (figure 5): Mendota Dam (~ RM 204.7) to Sack Dam (~ RM 182). Reach 3 is primarily a sandy bottomed, braided channel with limited streamside vegetation. Most of the river flows through agricultural land, except where it borders Firebaugh (~ RM 193 – 197). Sampling in this Reach was from below Mendota Dam to Firebaugh and at Sack Dam. At Sack Dam, water from the SJR is diverted into the Arroyo Canal.

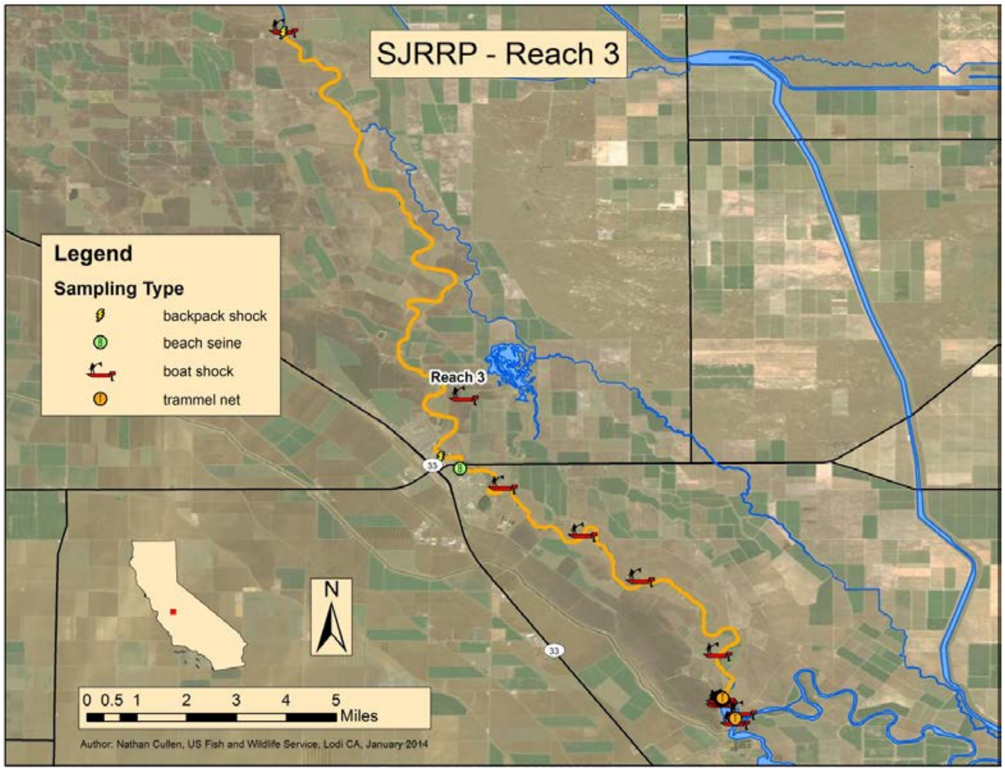


Figure 5.—Map of Reach 3 and associated sampling sites.

Reach 4 (figure 6): Sack Dam (~ RM 182) to confluence with the Eastside Bypass (~ RM 135.8). Reach 4 is subdivided into three sections: Reach 4A, Reach 4B1, and Reach 4B2. Reach 4A extends from Sack Dam to the Sand Slough control structure. Reach 4B1 is from the Sand Slough control structure to the Mariposa Bypass, and Reach 4B2 extends from here to the confluence with the Eastside Bypass. Most of the upstream area of Reach 4 is bordered by agricultural land, though, downstream of RM 151, resides in the boundaries of San Luis National Wildlife Refuge. Reach 4 has no flow during most of the year because of the diversion in Reach 3 into the Arroyo Canal. Some water seepage occurs at Sack Dam, though waters in Reach 4 are generally limited to rainfall and agricultural return.

Reach 5 (figure 7): Confluence with the Eastside Bypass (~ RM 135.8) to the confluence with the Merced River (~ RM 118). In addition to agriculture runoff from Reach 4, Reach 5 receives water inputs from the Eastside Bypass and Mud and Salt sloughs. Reach 5 also passes through San Luis NWR, then through state land including Great Valley Grasslands State Park and Freemont Ford State Recreation Area.

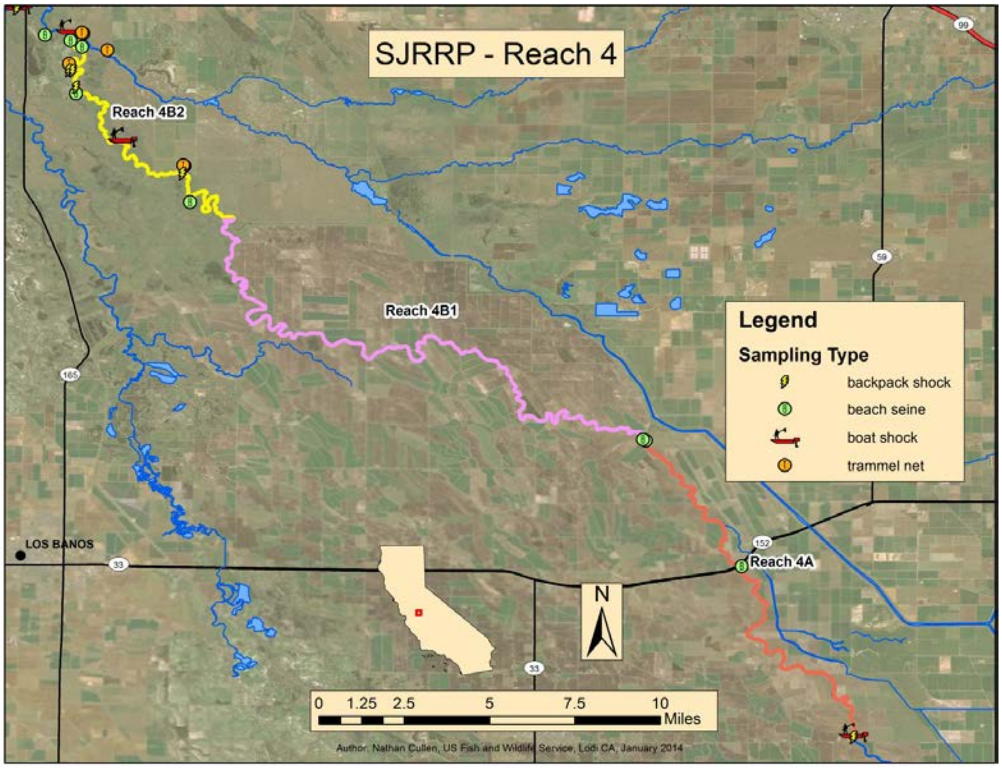


Figure 6.—Map of Reach 4 and associated sampling sites.

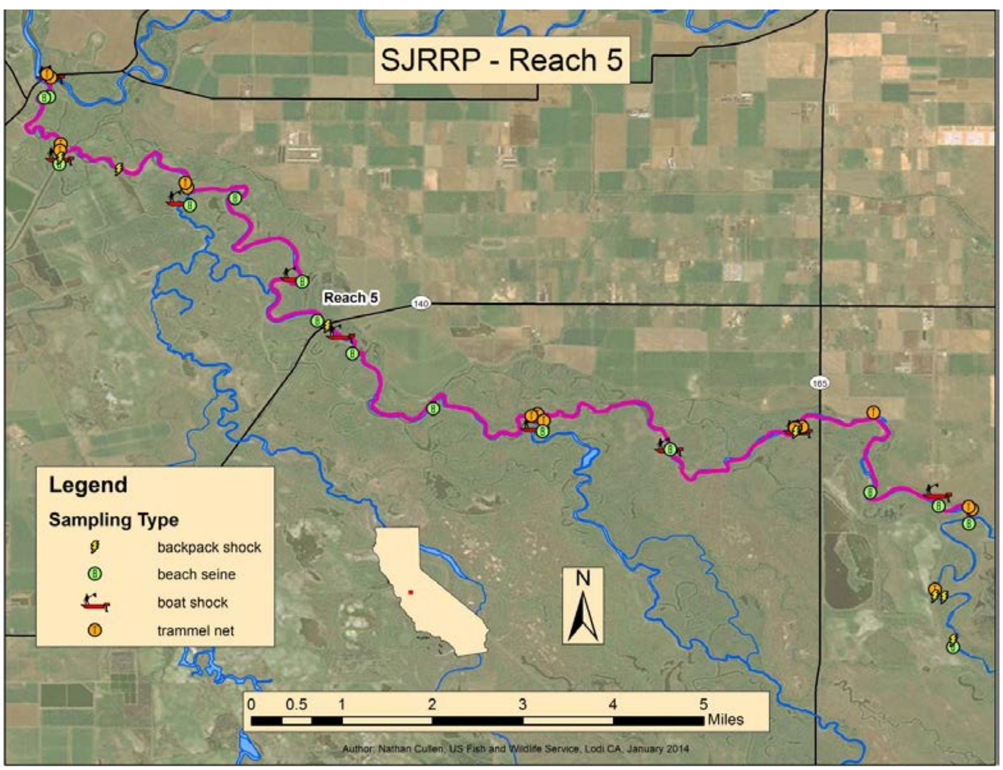


Figure 7.—Map of Reach 5 and associated sampling sites.

Initial sampling locations were based on prior habitat characterization (DFG 2007), site visits, and available land access. While an attempt was made to provide representative sampling of habitat types in the Restoration Area, there was an uneven distribution of sample sites across reaches (figures 2 – 7; tables 1 – 4). Specifically, sampling sites were more highly concentrated in Reach 1 and 5 than other reaches. Sampling sites were greater in Reach 1 because this reach contains the most habitat diversity (*e.g.*, runs, riffles, pools, glides). However, Reach 5 has several return flows from agricultural inputs that dramatically change the water quality through this reach. Fewer sampling sites occurred in Reach 2 and 3 because much of the riverine habitat in is relatively uniform. Sampling in Reach 4 is limited because of the river diversion into the Arroyo Canal at Sack Dam, restricting flows into this reach. Other factors precluding sampling included low water or dry river sections, or access restrictions limiting sampling (*e.g.*, boat launches, landowner permission).

Table 1.—Total sample locations, by restoration reach, during raft electrofishing efforts, October 2012 – June 2013

	October 2012	**January 2013**	**March/April 2013**	**June 2013**
Reach 1A	12	19	17	17
Reach 1B	3	5	5	5
Reach 2	3	5	4	4
Reach 3	7	7	8	8
Reach 4	0	2	1	1
Reach 5	12	13	9	10
Total	**37**	**51**	**44**	**45**

Table 2.—Total sample locations, by restoration reach, during backpack electrofishing efforts, October 2012 − June 2013

	October 2012	**January 2013**	**March/April 2013**	**June 2013**
Reach 1A	13	13	11	13
Reach 1B	6	5	5	6
Reach 2	4	4	4	4
Reach 3	1	1	1	1
Reach 4	2	4	4	8
Reach 5	1	3	3	4
Total	**27**	**30**	**28**	**36**

Table 3.—Total sample locations, by Restoration Reach, during seining efforts, October 2012 − June 2013

	October 2012	January 2013	March/April 2013	June 2013
Reach 1A	11	11	11	11
Reach 1B	5	5	5	4
Reach 2	1	1	1	1
Reach 3	1	1	1	1
Reach 4	5	6	5	6
Reach 5	4	12	12	12
Total	**27**	**36**	**35**	**35**

Table 4.—Total sample locations, by Restoration Reach, during trammel netting efforts, October 2012 – June 2013

	October 2012	January 2013	March/April 2013	June 2013
Reach 1A	9	15	14	14
Reach 1B	6	6	6	6
Reach 2	8	9	9	9
Reach 3	4	4	4	4
Reach 4	0	5	1	5
Reach 5	5	15	15	15
Total	**32**	**54**	**49**	**53**

Because an adaptive sampling routine was adopted during I&M efforts, sample locations were often dynamic. While there was an attempt to include sample sites that encompass habitat types in the Restoration Area, locations were added or removed under certain circumstances. Factors that influenced these decisions were the need for additional sampling transects within a Restoration Reach; for example, sample locations were added in Reach 4 for certain sampling methods because it was underrepresented. Conversely, the number of sample locations was reduced in some sections because habitat types were already represented. Additionally, some sample transects were relocated or not sampled due to environmental limitations (*e.g.*, low water levels/exposed riverbed/overhanging vegetation in previous sample areas, precluding or requiring relocation of sampling locations).

Sampling Methods

Several sampling methods were used during I&M surveys. Electrofishing was conducted by boat and backpack. Fish were actively collected by seining and passively collected with trammel and fyke nets, though fyke netting was not feasible during all sampling intervals (because of low water) and was ultimately discontinued for I&M efforts. Electrofishing and seining are considered active fishing methods because these methods target fish with moving gear (Murphy and Willis 1996). Trammel and fyke nets are considered passive fishing because nets are placed in stationary positions for extended periods of time (*e.g.*, 24 h), and personnel are not required to be present; these methods capture fish traveling through a study area as opposed to methods where the gear is actively moving. Though sampling by these methods is often more efficient at night (Bonar *et al.* 2009), all efforts were conducted during daylight hours for safety reasons. Raft electrofishing was conducted by BOR personnel. Raft electrofishing was selected to cover larger sections of river in a shorter duration than possible by other methods, and allowed sampling a variety of habitat types, as well as deeper waters where the use of other methods (*e.g.*, seining, backpack electrofishing) was not feasible. Also, raft electrofishing permitted sampling sections of river that were not accessible, either due to restricted landowner access or otherwise inaccessible by vehicle, preventing equipment transport to the river. Backpack shocking was conducted by US Fish & Wildlife Service (FWS) and Bureau of Reclamation (BOR) personnel. Backpack electrofishing was selected for shallow, near-shore areas, particularly in areas too shallow for trammel nets or too vegetated for deploying trammel nets or seining, as well as higher velocity shallow areas (*e.g.*, riffles). Seining was conducted by FWS personnel. Like backpack electrofishing, seining was conducted in shallow, near-shore areas. However, seining is typically conducted in areas with low velocities and minimal obstructions (*e.g.*, debris, vegetation, uneven substrate) that could cause snags; the benefit of seining is that a large area can be sampled within a short time period, and smaller fish, which electrofishing can bias against, are captured with a greater frequency (Wiley and Tsai 1983; Murphy and Willis 1996). Quarterly surveys, using these gear types, took place in October 2012, January, March/April, and June 2013.

Raft Electrofishing

Personnel, consisting of an operator responsible for raft navigation and electrofishing controls, and two crew members responsible for fish collection, surveyed Restoration Reaches using a Smith-Root SR-17 electrofishing raft with a 5.0 GPP electrofisher (Smith-Root Inc., Vancouver, WA). The raft-mounted electrofishing unit automatically adjusts pulse width (1-6 ms) based on user specified inputs, including: voltage type (AC/DC), output voltage (Low: AC/DC 50-500 V, or High: 0-1000 V AC), percent of power output, and pulse frequency (pulses/second). The low range (0-500 V, pulsed DC) was almost always selected, though the high range was infrequently used in upstream reaches with low water conductivity (<50µS/cm). Maximum current by the 5.0 GPP electrofisher is 16 A, but amperage was maintained 3 – 8 A during shocking activities.

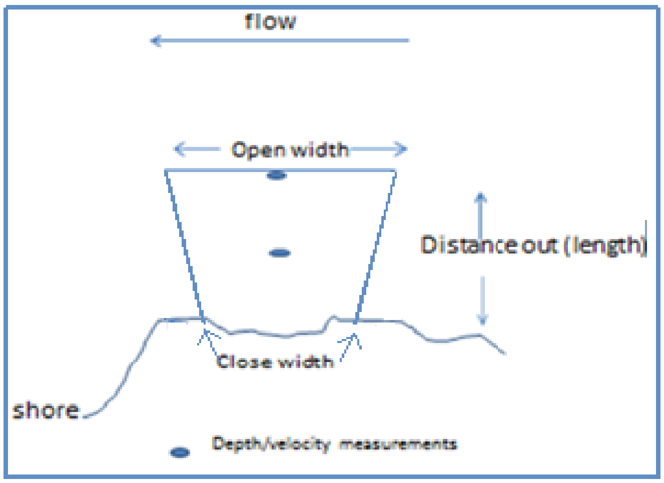
During electrofishing, power output (as a percentage of total output, as well as pulses/s) was adjusted based on observations of fish behavior and water conductivity. Optimal fish response was positive axis towards the anode, as opposed to galvanonarcosis which could preclude collection in deep or turbid water and potentially increase injury to fish. During operation, as fish entered the netting perimeter of the raft, they were collected and placed in a water-filled container onboard. Concluding each sampling period, fish were measured (mm fork length/total length; FL/TL), weighed (g), and returned to the river. Start and end coordinates (UTM) were recorded for each sampling transect using a handheld GPS unit. The following electrofishing data were recorded: total shock time, current type (AC/DC), voltage range, percent output (0-100%), amperage, and pulse frequency. Additionally, water quality data were recorded for each sample transect, including: temperature (°C), dissolved oxygen (DO; mg/L), conductivity (µS/cm, microSiemens/centimeter), and turbidity (nephelometric turbidity units, NTU).

Backpack Electrofishing

A Smith-Root LR-24 backpack shocker was used in habitats with complex structure and shallow depths. In pool and glide habitats, electrofishing was conducted in an upstream direction with a netter following the electrofisher. In riffle habitats, a seine block net was set at the base of the habitat and electrofishing was conducted downstream into the block net. Single-pass pulsed-direct current was used at all sites. Amperage, frequency, duty cycle, and voltage settings were determined before starting and set at minimum power levels needed to induce tetany in fish. After sampling each site, fish were measured (mm, FL/TL), weighed (g), and returned to the river. If more than twenty individuals of a species were captured, only twenty were weighed and measured and the rest were enumerated. Site conditions recorded included percent cloud cover, precipitation presence, wind, and habitat type. Physical measurements taken included transect length, width, and depth. Turbidity, temperature, DO, total shock time, flow, and site coordinates were also recorded.

Seining

Beach seining was conducted using a 15.24m × 1.22m, 3.175mm delta-mesh net. Seines were dyed green to reduce visibility to fish. Seining was primarily used in shallow areas with little to no current and free from snags. Two people set the seine parallel to the shore while staying as far away as possible from the area to be sampled until the net was deployed. The seine was deployed from the downstream end, if in current. The appropriate open width and distance from shore were determined by site conditions (*e.g.*, depth, debris, current). After the seine was fully deployed, it was slowly brought to shore, keeping the lead line on the bottom. Markers were dropped where the seine poles met the shoreline. Then the seine was retrieved out of water to collect fish. To determine sampling area, the distance the net was deployed out from the bank (length), open width, and close width were measured (figure 8). Starting depth and mid-seine depth were measured. End depth was always zero. Total volume of water sampled was calculated as the area of the trapezoid times the average of the three depth measurements. Fish captured by seine were processed in the same manner as backpack shocking. The same site data recorded during backpack shocking were also recorded at seine sites.



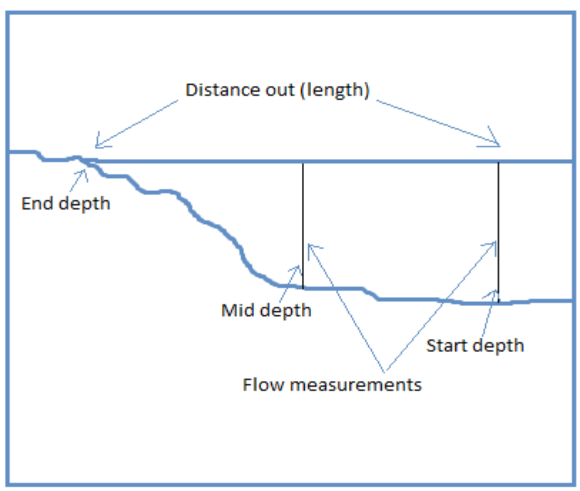


Figure 8.—Schematic of seine deployment and measured dimensions. The aerial view of the seining dimensions is presented on top. The cross-sectional area of the seining dimensions is depicted on bottom.

Netting

Netting surveys were conducted in the Restoration Area using trammel and fyke nets (H. Christiansen Co., Duluth, MN). Trammel nets were between 11.4 − 30.5 m (37.5 – 100 ft.) long and 0.9 – 1.8 m (3 – 6 ft.) tall. Trammel nets were generally deployed from watercraft (*i.e.* Jon boat or kayak), in pools and often near structures (*e.g.*, rock weirs, dams, abandoned in-river gravel pits). Nets were either tied to overhanging vegetation near shore and extended into the sample area or suspended in the water column, extending upwards from the substrate with a series of buoys and weights. Nets were retrieved the following day, with a nominal sample period of 24 h. Upon retrieval, fish were removed from the nets, enumerated, measured (mm, FL/TL), and returned to the waterway. Other details recorded included coordinates (UTM), net size, and total netting duration.

Data Collection and Analysis

Water Quality and Flow Data

To present temperature (°C), DO (mg/L), turbidity (NTU), and conductivity (µS/cm) across the Restoration Area, data is presented for sample locations in the mainstem SJR, using data recorded during raft electrofishing. Though sampling occurred in some return flows (*e.g.*, James Bypass, Salt Slough, Newman Wasteway), data collected in these areas were omitted from the results, unless sample transects terminated in the mainstem SJR. The RM of each sampling transect was determined and the associated data were graphed accordingly. Temperature data are organized by RM and month and presented in the Results section. Because of equipment complications, dissolved oxygen data collected during raft electroshocking was also supplemented with data supplied from the California Department of Water Resources' (DWR) Data Exchange Center (http://cdec.water.ca.gov/index.html). Data were supplied via 6 sensors (3 DWR, 3 BOR; Appendix A) in the SJR from Friant Dam to the confluence with the Merced River. Because water quality data were supplied from raft electrofishing events, data concurrent with these dates was downloaded from the Data Exchange Center. Raft electrofishing generally occurred over a 2-week period. Dissolved oxygen data, corresponding temporally to raft electrofishing in that particular river section was downloaded. If a flow sensor was located outside a sampling section, flow data were evaluated for the day corresponding to the nearest raft electrofishing sample day (*e.g.*, a flow sensor is located downstream of Hwy 41, Reach 1, but raft electrofishing occurred to, but not past Hwy 41; so flow data from that sensor was downloaded during the dates of raft electrofishing from Scout Island to Hwy 41). These sensors generally record data at 15- to 60-min intervals. However, daily averages were calculated, and are presented in the Results.

Flow data were also collected from the California Department of Water Resources' (DWR) Data Exchange Center. Flow data were supplied via

13 sensors (3 DWR, 5 BOR, 4 US Geological Survey (USGS), and 1 jointly operated by DWR and USGS; Appendix A) in the SJR from Friant Dam to the confluence with the Merced River. Data collected from these sensors were evaluated in a similar manner as the DO data described in the previous paragraph.

Species Detection

During each sampling event, independent of method, species and total numbers of fish were recorded. Fish not identified to species (*e.g.*, juvenile fish, hybrid species) were identified to genus. Fish captured by raft electrofishing were generally weighed (g) and measured (mm, FL/TL). However, fish < 10 g or < 50 mm were generally not weighed because field conditions prevented accurate measurement with available equipment (*e.g.*, wind, excess water, accuracy of scale). Likewise, fish captured with a seine or backpack electrofisher were measured (mm, FL/TL) and weighed (g). Fish captured by the other sampling methods were typically measured only for length (mm, FL/TL). In some cases, when large numbers of fish were captured, a subset was measured and the remaining fish enumerated. Presence of species, independent of method, was organized by sampling season and Restoration Reach. Results are presented below.

Catch-per-Unit-Effort

Catch-per-unit-effort (CPUE) was selected as an index to evaluate changes in fish communities over time. The benefit of using CPUE over abundance estimates are that CPUE indices can be derived without having to account for differences in fish catchability (Weaver *et al.*1993; Lyons 1983). Measuring species' abundance would require a catchability index be derived for different species and sampling methods across Restoration Reaches (Arreguín-Sánchez 1996); obtaining this index would require more extensive efforts than currently feasible. Furthermore, because sampling efforts were not equally distributed across Restoration Reaches (tables 1 − 4), a direct comparison of total fish captured between reaches would be misleading. CPUE was calculated to standardize disproportionate sampling efforts across time and/or area.

Because inherent biases exist across sampling methods (Murphy and Willis 1996; Bonar *et al.* 2009) and capture efficiency may vary seasonally by species (Pope and Willis 1996), CPUE was calculated for each sample method and time period. For example, electrofishing generally has a bias towards capture of larger fish, scaleless and small-scaled fish, and a negative bias towards small and benthic fish (Murphy and Willis 1996; EPA 2000; Bonar *et al.* 2009). Likewise, netting presents a bias towards capture of larger, actively swimming fish and against small and inactive fish (Murphy and Willis 1996). Small fish may be underrepresented when using netting gear types because these fish may pass through the net material; active fish are more likely to be captured than inactive fish (Weaver *et al.* 1993). Seining generally captures small bodied or juvenile fish that reside in the littoral zone (Bonar *et al.* 2009). Sampling efforts across seasons may not be directly comparable either (Pope and Willis 1996). Seasonal differences may affect fish behavior/metabolic levels, which can affect capture efficiency. It does not necessarily mean they are more abundant at one time of year and not another. Evaluating these differences is beyond the scope of this study. For these reasons, fish captured during sampling efforts were independently evaluated by sampling method and season.

Though CPUE is not a direct measure of abundance, it may be used to evaluate changes in fish assemblages as Restoration efforts continue. CPUE allows comparison, within each sampling method, while accounting for the uneven distribution of sampling events (*e.g.*, varying electrofishing times between transects or net-set times), or size differences within gear types or sample area (*e.g.*, varying trammel net sizes). Within each Reach, CPUE was calculated for each sampling event/location; a sampling event consisted of either an electrofishing transect, volume of water seined, or the area and duration of a trammel net set. For calculation of CPUE, each sampling event was evenly weighted within its respective Restoration Reach.

Before calculation of CPUE, fish were grouped by family (*e.g.*, Catostomidae, Salmonidae, Moronidae). Centrarchidae were further divided into two subgroups: *Lepomis/Pomoxis* (sunfish/crappie) and *Micropterus* (black bass). Cyprinidae were subdivided into native (*e.g.*, hitch, *Lavinia exilicauda*, Sacramento pikeminnow, *Ptychocheilus grandis*) and nonnative (*e.g.*, common carp, *Cyprinus carpio*, red shiner, *Cyprinella lutrensis*) groups. Lastly, fish with few representative species, including only nonnative fishes, were broadly grouped into an “Other” category. Fish in this category include bigscale logperch (*Percina macrolepida*), inland silverside (*Menidia beryllina*), goby *spp.* (Gobiidae), threadfin shad (*Dorosoma petenense*), and western mosquitofish (*Gambusia affinis*).

To compare fish distribution across Restoration Reach by sample method (*i.e.*, raft electrofishing, backpack electrofishing, seining, trammel netting) and season, CPUE was calculated by $\frac{1}{n}\sum_{i=1}^{n} f(x)_{(\text{method})}$, where:

$f(x)_{\text{electrofishing}} = \frac{x_c}{t_i}$, where x_c = number of fish in group *c* (*e.g.*, Family), *t* = shock time (s) for transect *i*, and *n* = total shocking transects within the defined Restoration Reach. Units for CPUE are fish/minute shock time;

$f(x)_{\text{seining}} = \frac{x_c}{\text{m}_i^3}$, where x_c = number of fish captured in group *c*, m_i^3 = volume of water in sample *i*, and *n* = total seining events within the defined Restoration Reach. Units for CPUE are fish captured/m^3;

$f(x)_{\text{trammel net}} = \left(\frac{x_c/\mathrm{m}_i^2}{t_n}\right)$, where x_c = number of fish captured in group c, m_i^2 = area of the net used during net sampling event i, and n = total netting events within the defined Restoration Reach. Units for CPUE are reported as fish captured/m^2 (net area)/day.

RESULTS

Water Quality and Flow Data

During all sampling periods, except for January 2013, recorded river temperatures generally increased downstream through the Restoration Area (figure 9). From Reach 3 downstream, temperatures regularly exceeded 20°C in all sample months except January 2013. The highest temperatures, across all sample periods occurred in June 2013, with temperatures in Reach 5 exceeding 30°C. Unlike the other sample periods, though, temperatures in January 2013 generally decreased from up- to downstream in the Restoration Area; temperatures near Friant Dam were ~10°C and were as cool as 5.5°C in Reach 5. Likewise, river temperatures were the least variable in January 2013 with a range of only ~ 5.6°C (5.5 – 11.1°C). The greatest fluctuation in recorded temperatures occurred in June 2013 (10.8 – 31.3°C, range 20.5°C). Temperatures varied from 9.2 – 23.6°C in March/April 2013 (range 14.4°C). Temperatures in October 2012 varied from 12.2 – 25.6°C (range 13.4°C). Across all sampling periods, temperatures at Friant Dam were least variable (9.3 – 13.5°C, range 4.2°C), while temperatures in Reach 5, were most variable (6.4 – 31.3°C, range 24.9°C).

While DO was not dramatically different from upstream to downstream reaches, variability across sampling periods was generally less in upstream reaches (figure 10). In general, across all sampling periods, turbidity and conductivity increased from upstream to downstream (figures 11 – 12).

Across all sampling seasons, recorded flows generally decreased downstream to Sack Dam (figure 13), where nearly all of the SJR is diverted into the Arroyo Canal. Conversely, flows recorded from the DWR sensor near Stevinson (Station ID: SJS), showed increasing flows downstream to the confluence with the Merced River. In Reach 1 – 4, recorded flows were greatest in March/April 2013 and lowest in October 2012 and June 2013. Flows in Reach 5 were greatest in January 2013 and lowest in October 2012. A flow sensor downstream of Mendota Dam (USGS station ID: MEN) indicates an increase in flows in October 2012 and June 2013 from the upstream sensor near the Chowchilla Bifurcation Structure (Station ID: SJB), though flows are lowest below Sack Dam for the same time period.

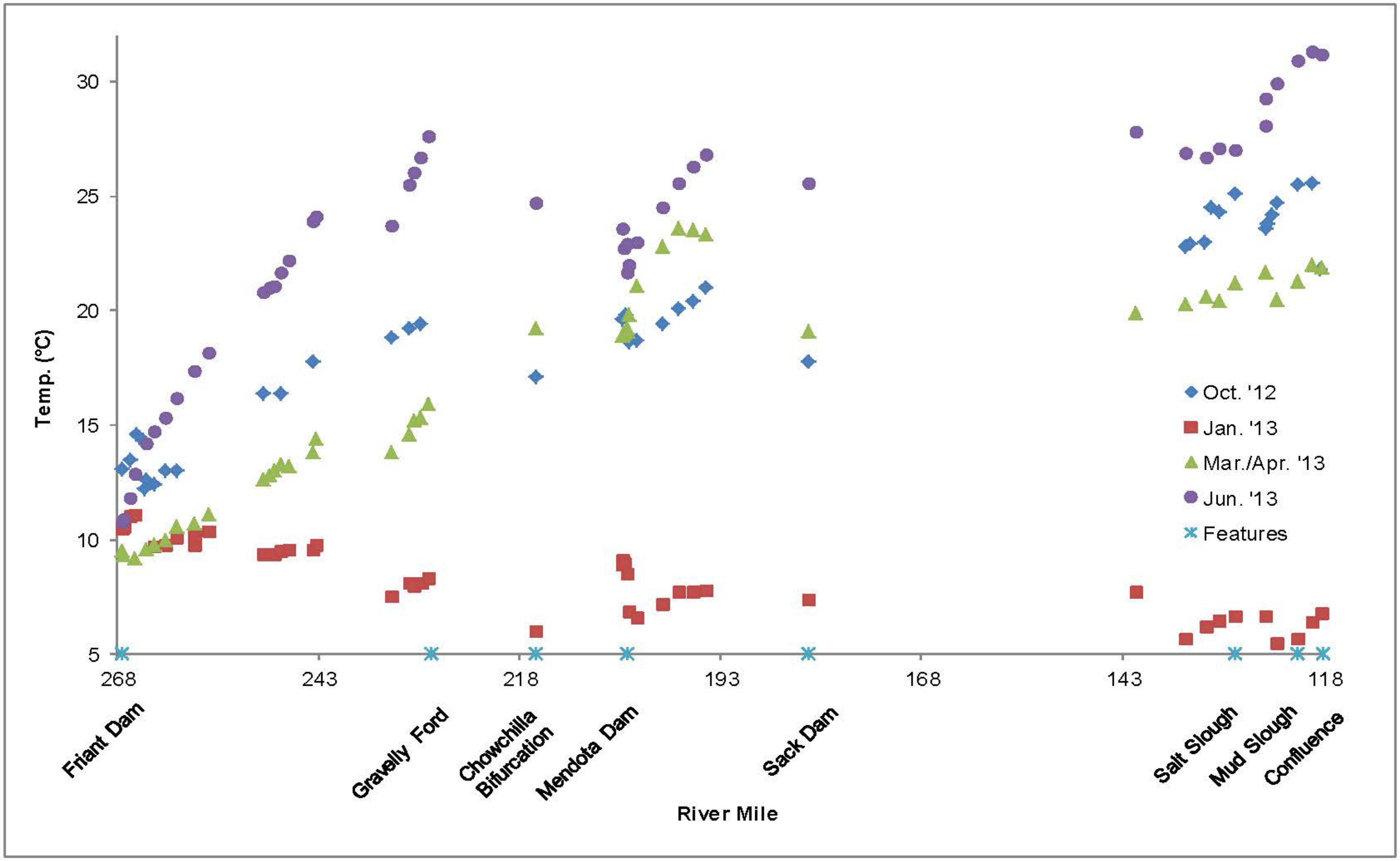


Figure 9.—Water temperature (°C) at sample locations in the San Joaquin River during raft electrofishing efforts during October 2012, January, March/April, and June 2013. "X" markers on x-axis denote locations and description, respective to river mile, of structures or features in the Restoration Area.

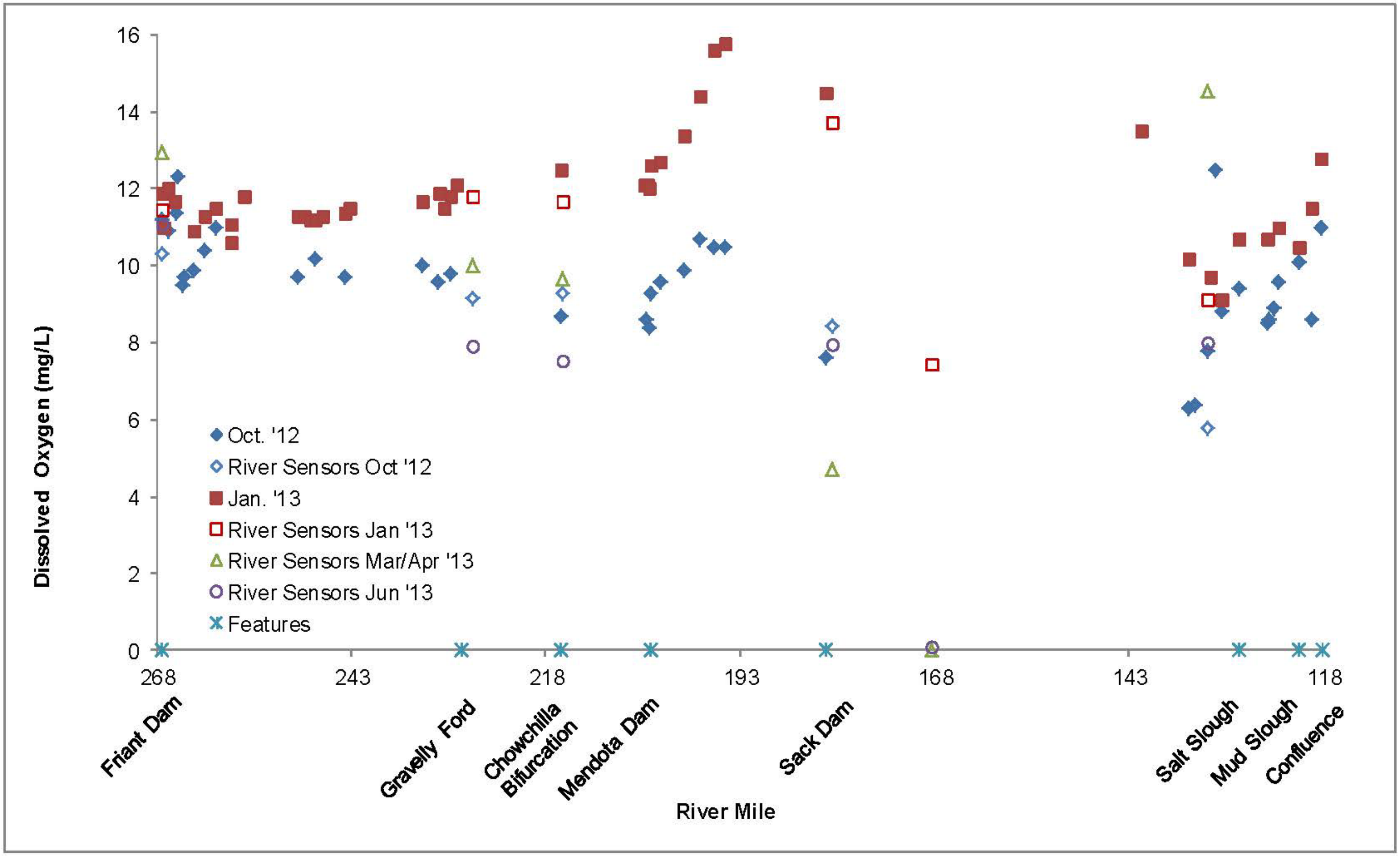


Figure 10.—Dissolved oxygen (mg/L) at sample locations in the San Joaquin River (SJR) during raft electrofishing efforts during October 2012 and January 2013. River sensor values are daily averages coinciding with raft electrofishing events during the Inventory and Monitoring period, calculated from 15- to 60- minute interval values recorded at six sensors, maintained by California Department of Water Resources and Bureau of Reclamation, in the SJR. "X" markers on x-axis denote locations and description, respective to river mile, of structures or features in the Restoration Area.

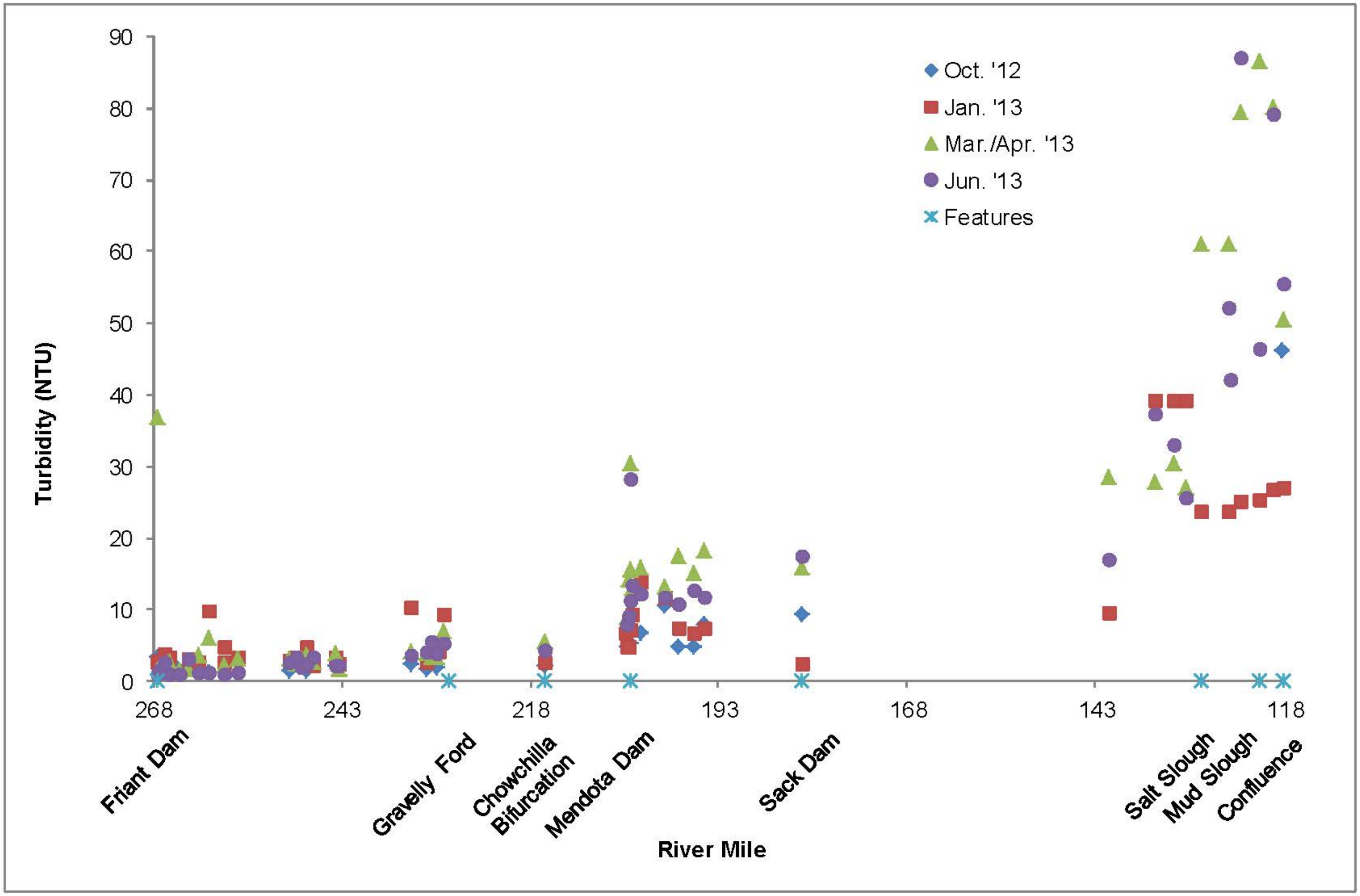


Figure 11.—Turbidity (NTU) at sample locations in the San Joaquin River during raft electrofishing efforts during October 2012, January, March/April, and June 2013. "X" markers on x-axis denote locations and description, respective to river mile, of structures or features in the Restoration Area.

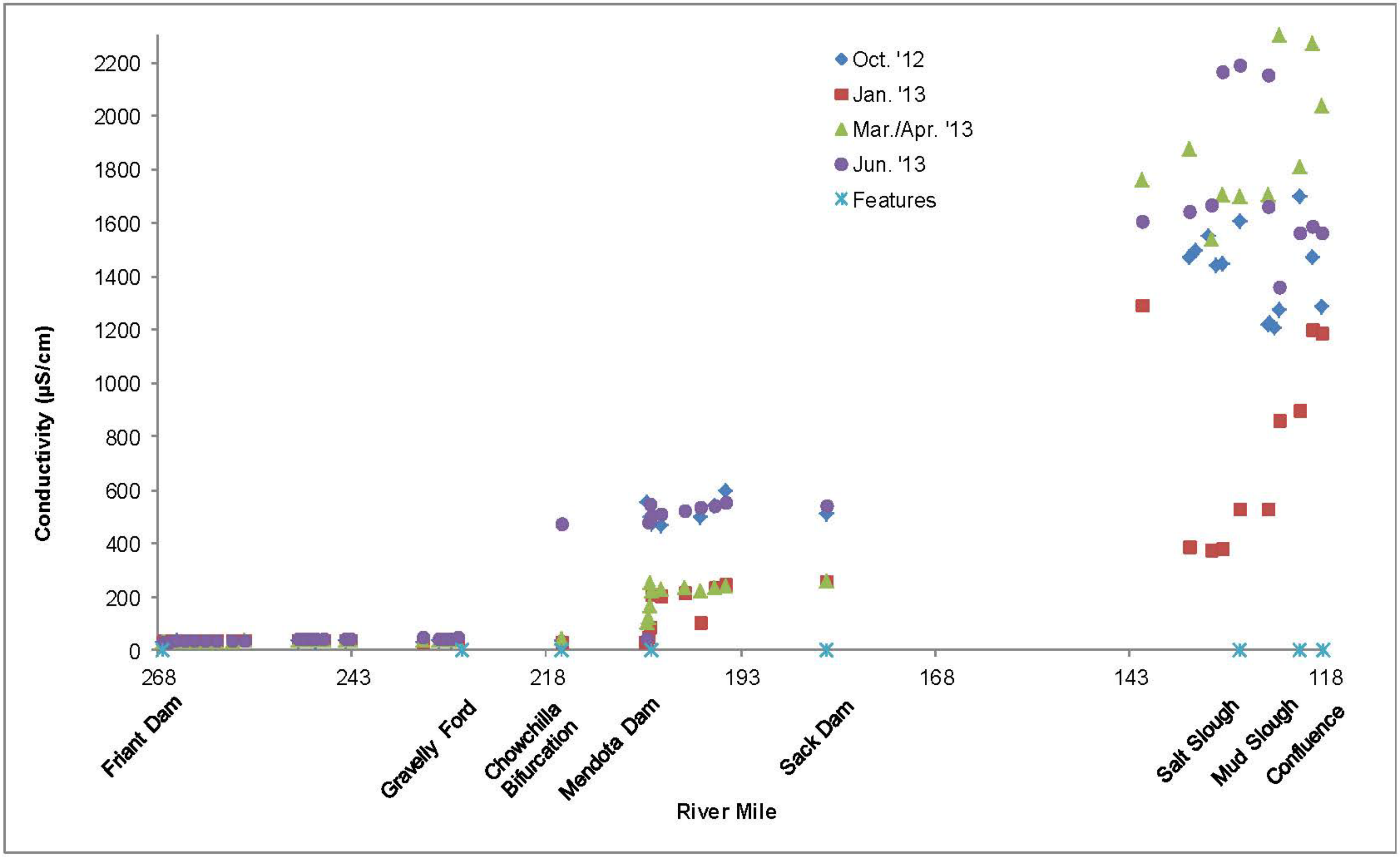


Figure 12.—Conductivity (µS/cm) at sample locations in the San Joaquin River during raft electrofishing efforts during October 2012, January, March/April, and June 2013. "X" markers on x-axis denote locations and description, respective to river mile, of structures or features in the Restoration Area.

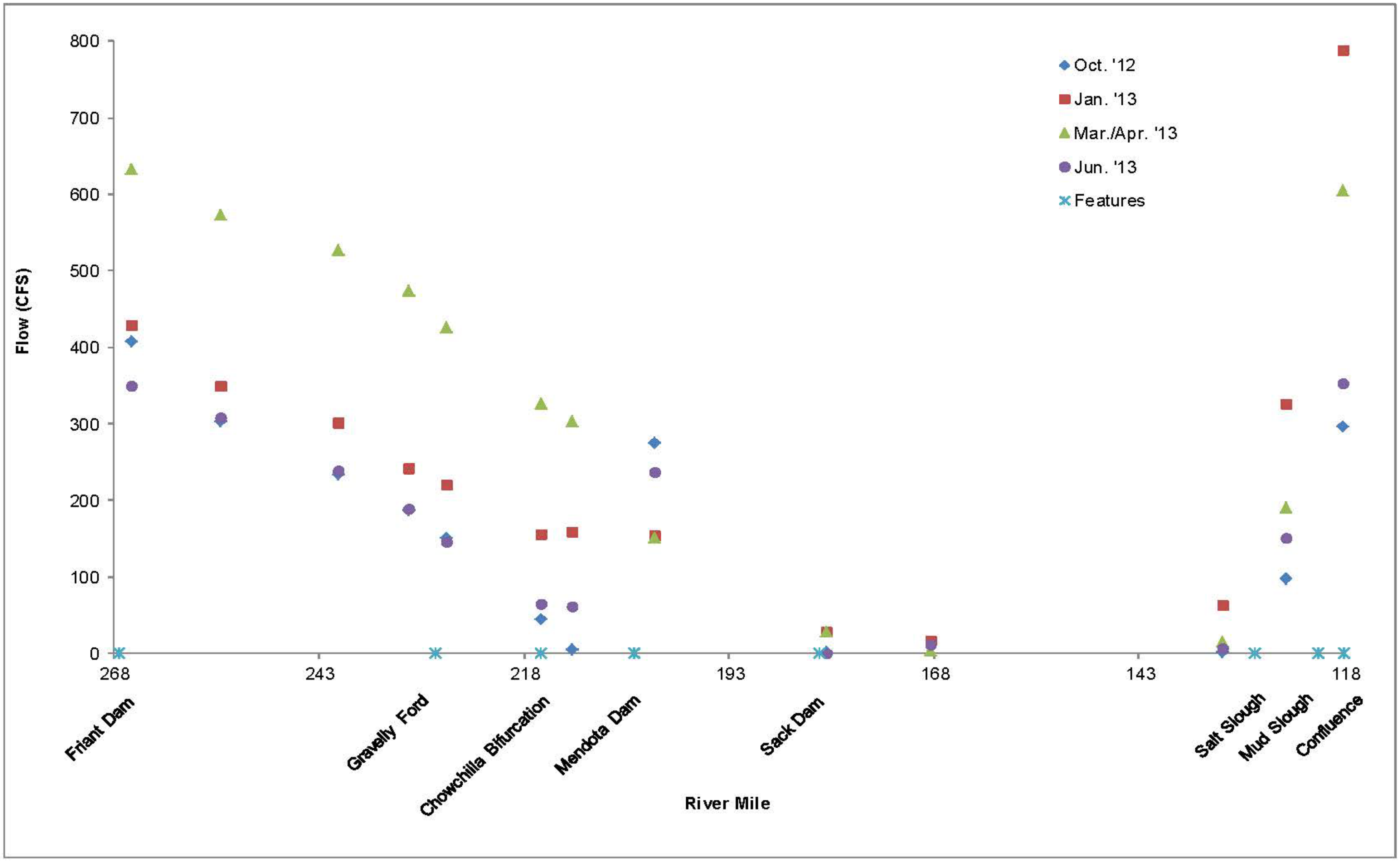


Figure 13.—Average daily flow (CFS) in San Joaquin River (SJR) during Inventory and Monitoring surveys in October 2012, January, March/April, and June 2013. Daily averages calculated from 15-min interval values recorded at thirteen sensors in SJR, maintained by California Department of Water Resources, U.S. Geological Survey, and Bureau of Reclamation. "X" markers on x-axis denote locations and description, respective to river mile, of structures or features in the Restoration Area.

Species Detections

Species detections, across Restoration Reaches, are presented in table 5. Generally, native fish occurred most frequently in upstream reaches, while nonnative fish were more frequently encountered in downstream reaches. Specifically, hardhead (*Mylopharodon conocephalus*), lamprey (*Lampetra spp.*), rainbow trout (*Oncorhynchus mykiss*), Sacramento pikeminnow, and threespine stickleback (*Gasterosteus aculeatus*) were exclusively found in Reach 1A. Prickly sculpin (*Cottus asper*) and Sacramento sucker (*Catostomus occidentalis*) were found in all reaches, during at least one of the sampling efforts from October 2012 – June 2013. Hitch occurred in Reach 1A, 2, and 5. Sacramento blackfish (*Orthodon microlepidotus*) and Sacramento splittail (*Pogonichthys macrolepidotus*), though, were never captured in Reach 1, and only recovered in Reach 3 − 5 and Reach 2 and Reach 5, respectively.

While all species of the following families, present in the Restoration Area, were not found in all reaches, at least one representative species was found in Reach 1 – 5: Centrarchidae (including *Lepomis*, *Micropterus*, and *Pomoxis spp.*), Ictaluridae, non-native Cyprinidae, and Poeciliidae (mosquitofish). Striped bass (*Morone saxatilis*) and bigscale logperch were found in Reach 2 – 5. Inland silverside were found in Reach 3 – 5. Threadfin shad were found in Reach 2 and 5. A shimofuri goby was found in Reach 2.

Catch-per-Unit-Effort

Catch-per-unit-effort data are presented on figures 14 – 29.

DISCUSSION

This was the first year of monitoring efforts. These data will serve as the baseline for monitoring changes in the fish community as restoration efforts progress, particularly regarding the Restoration Goal of restoring fish populations to good conditions. Restoration efforts will be adaptive based, partially on fish community changes in response to salmon reintroduction, flow changes, construction projects, and habitat improvement. Changes in the fish community may occur across all Restoration Reaches. As adult salmon are reintroduced and juveniles increase via natural or hatchery production, this could lead to competition between young-of-year salmon and the current fish assemblage for food and rearing habitat. Likewise, diet shifts of predators from current fish populations may occur with the introduction of seasonally abundant prey (*e.g.*, juvenile salmonids; Vigg *et al.* 1991). Major construction projects may also occur within the Restoration Area, including alterations to the Sand Slough Control Structure, Mendota Dam, Sack Dam, and the Arroyo canal to increase the capacity for water conveyance, to facilitate up and downstream fish movement,

Table 5.—Presence/absence of species in restoration reaches, independent of method

Species	Reach					
	1A	1B	2	3	4	5
Bigscale Logperch			SP	F SP S	F W	F W SP
Black Bullhead	F W	SP	SP	SP		W SP S
Black Crappie	F W S	F	F W SP S	F S	F W SP S	F W SP S
Bluegill	F W SP S	F W SP S	F W SP S	F W SP S	F W SP S	F W SP S
Brook Trout	F					
Brown Bullhead			F W S	F	S	SP S
Channel Catfish	S	F W S	F W SP S	F W SP S	W SP S	F W SP S
Chinook Salmon	S					F
Common Carp	F W SP S	W SP S	F W SP S	F W SP S	W SP S	F W SP S
Fathead Minnow					SP S	F W SP S
Golden Shiner	W S	W	W SP S	F W SP	F	F W SP
Goldfish	S		W SP S	F W SP S	SP S	F W SP S
Green Sunfish	F W SP S	F W S	F W SP S	F W SP S	W SP S	F W SP S
Hardhead	F					
Hitch	W		F SP S	F SP		
Inland Silverside				W SP S	F W SP S	F W SP S
Lampetra spp.	F W SP S					
Largemouth Bass	F W SP S	F W SP S	F W SP S	F W SP S	F W SP S	F W SP S
Lepomis spp., hybrid					SP	SP
Mosquitofish	F W SP S	F W SP S	F W SP S	F W SP S	F W SP S	F W SP S
Prickly Sculpin	F W SP S	S	F SP	SP	F SP S	SP S
Pumpkinseed						F W
Rainbow Trout	F W SP S					
Red Shiner			W	SP	F W SP S	F W SP S
Redear Sunfish	F W S	F SP S	F W SP S	F W SP S	F W SP S	F W SP S
Redeye Bass						SP
Riffle Sculpin	SP			F		
Sacramento Blackfish				F W	W S	F W SP S
Sacramento Pikeminnow	F W SP S					
Sacramento Splittail			SP			W SP
Sacramento Sucker	F W SP S	F W SP S	W S	F W SP S	F W S	F W SP S
Shimofuri Goby			F			
Smallmouth Bass	W					
Spotted Bass	F W SP S	F W SP S	F W SP S	F W SP S	W SP S	F W SP S
Striped Bass			W SP S	SP	F SP S	F W SP S
Threadfin Shad			F			F W SP S
Threespine Stickleback	F W SP S					
Warmouth				SP S	W	S
White Catfish	SP S	F W SP S	F W SP S	F W SP S	F W SP S	F SP S
White Crappie					W	W S
	F-October, W-January, SP-March/April, S-June					

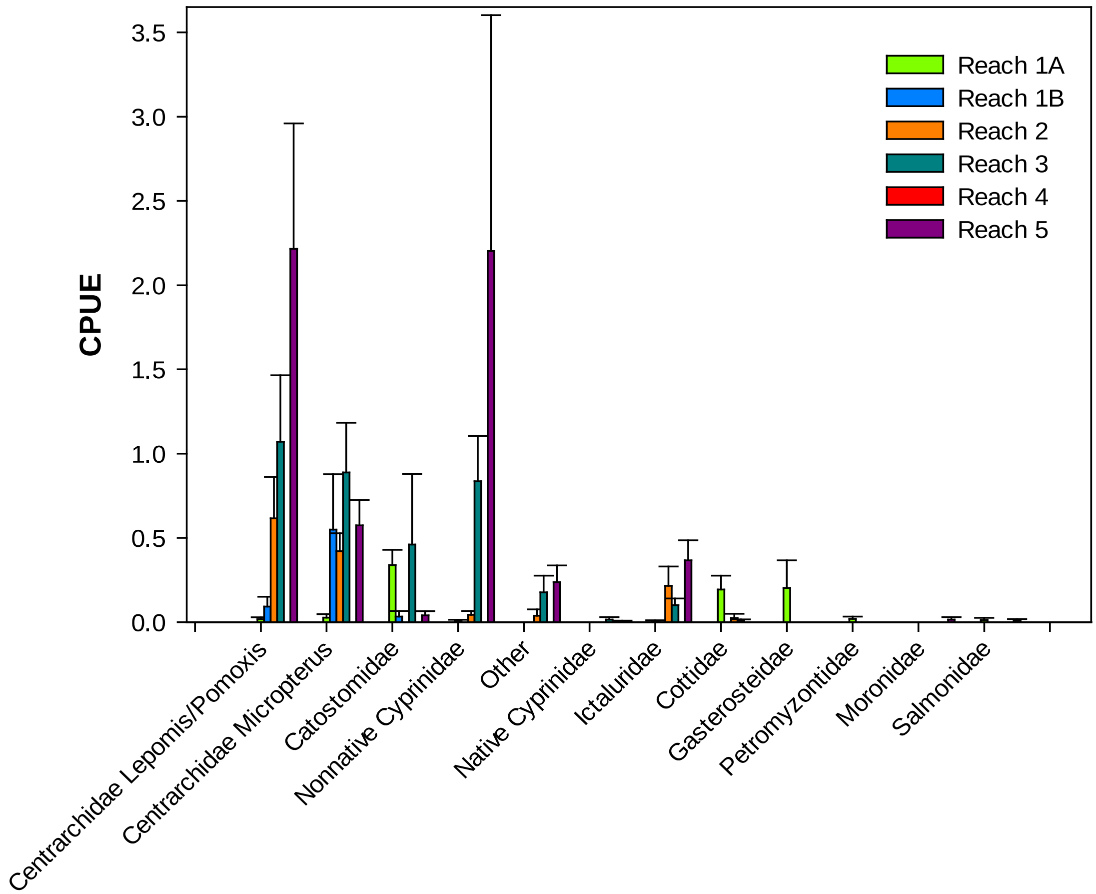


Figure 14.—Catch-per-unit-effort (CPUE; fish/minute shock time) during raft electrofishing October 2012. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE.

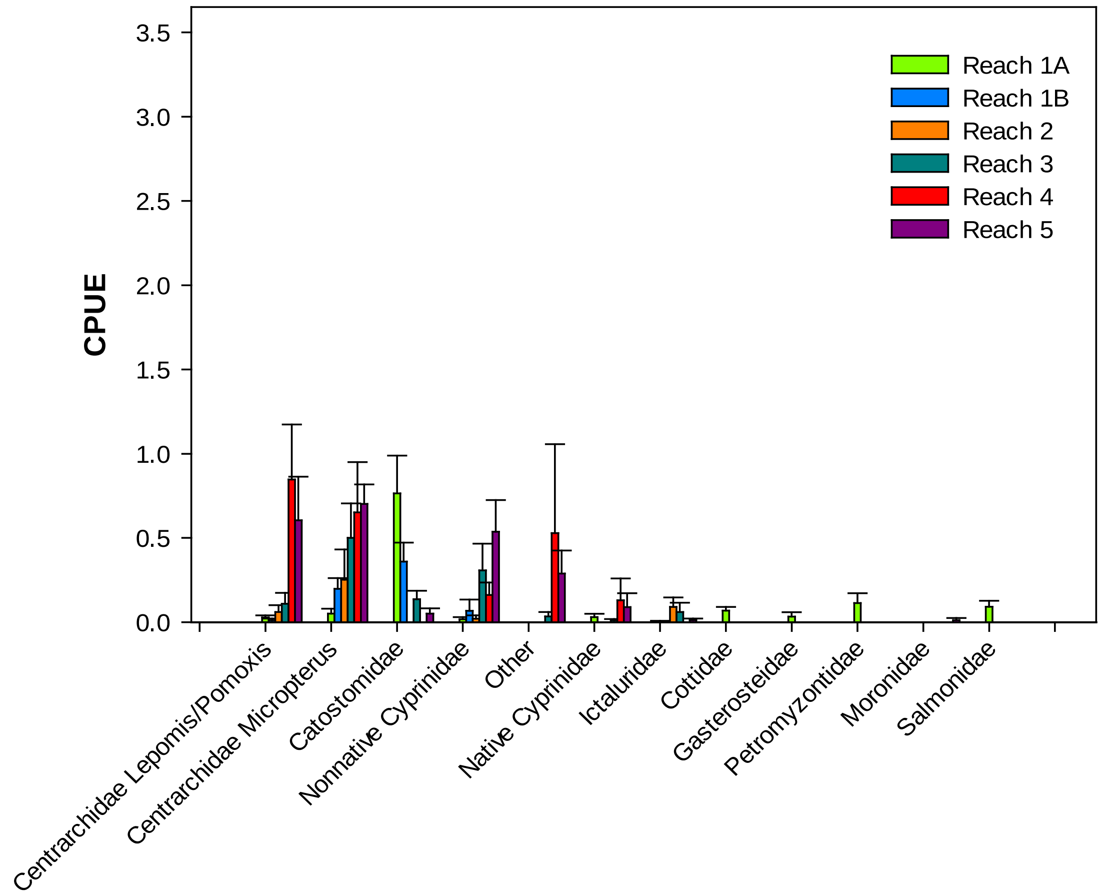


Figure 15.—Catch-per-unit-effort (CPUE; fish/minute shock time) during raft electrofishing January 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE.

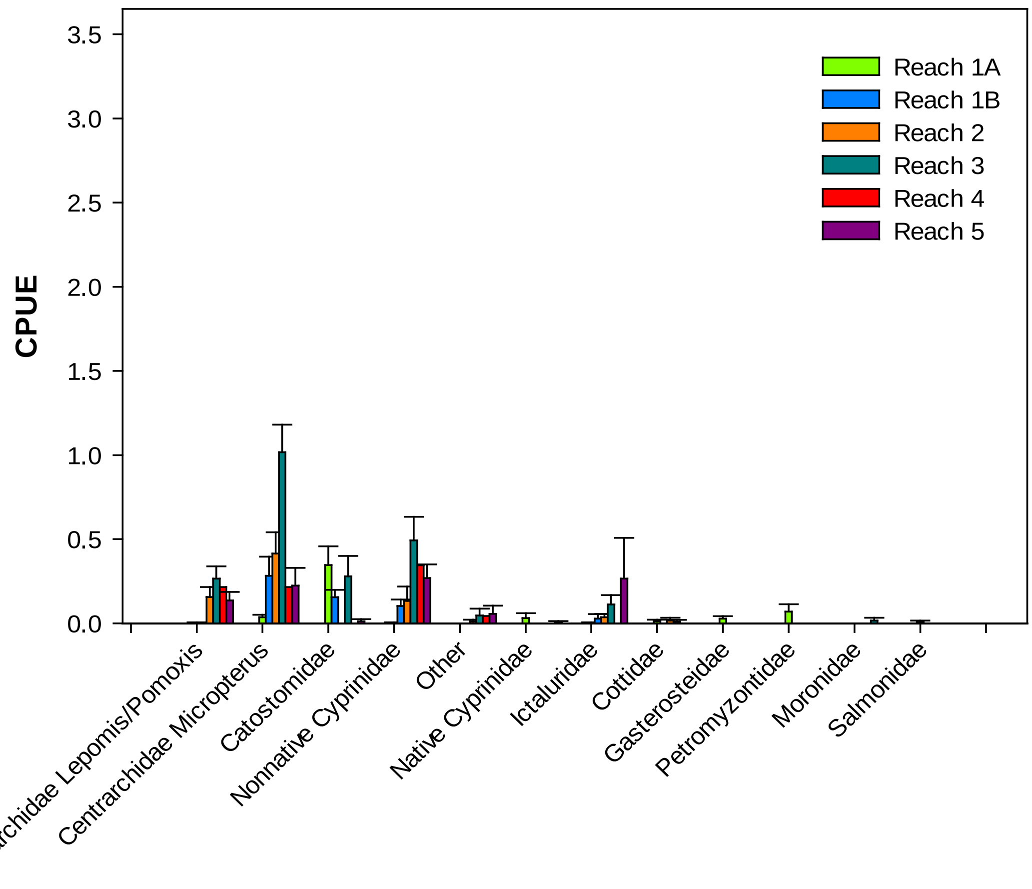


Figure 16.—Catch-per-unit-effort (CPUE; fish/minute shock time) during raft electrofishing March/April 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

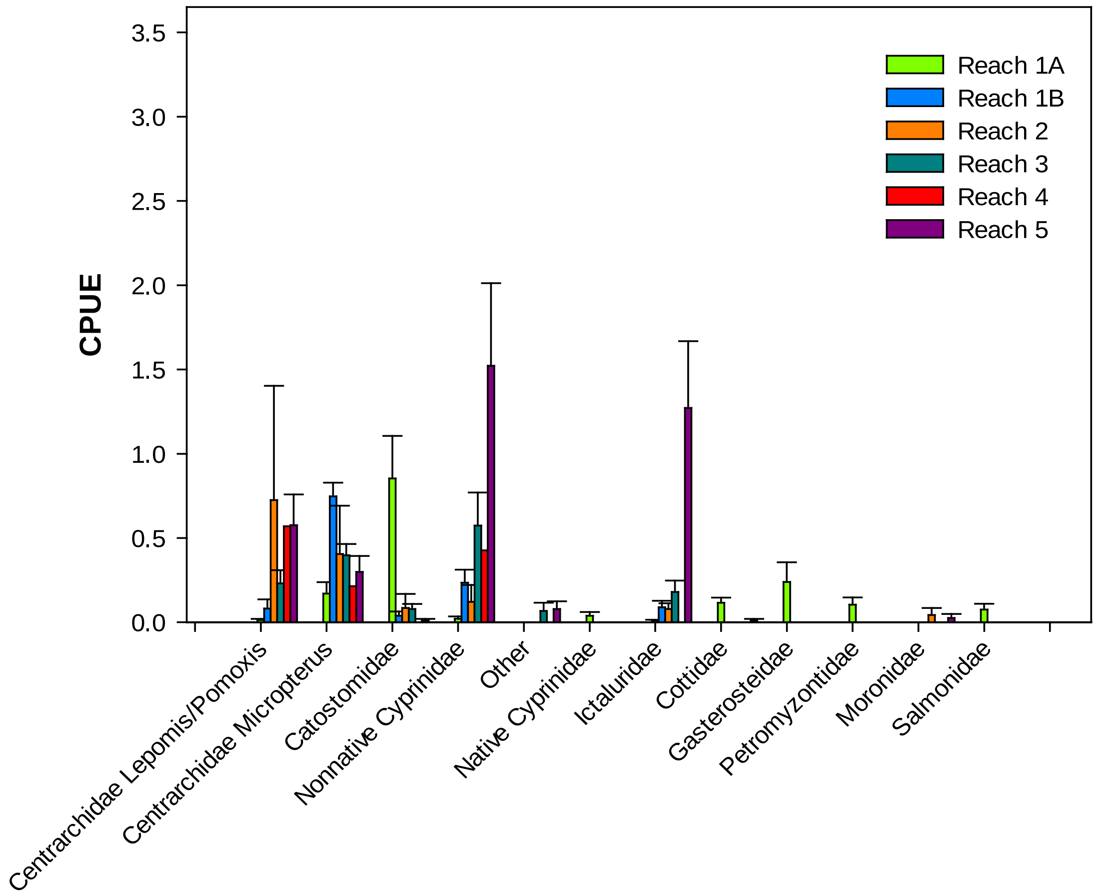


Figure 17.—Catch-per-unit-effort (CPUE; fish/minute shock time) during raft electrofishing June 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

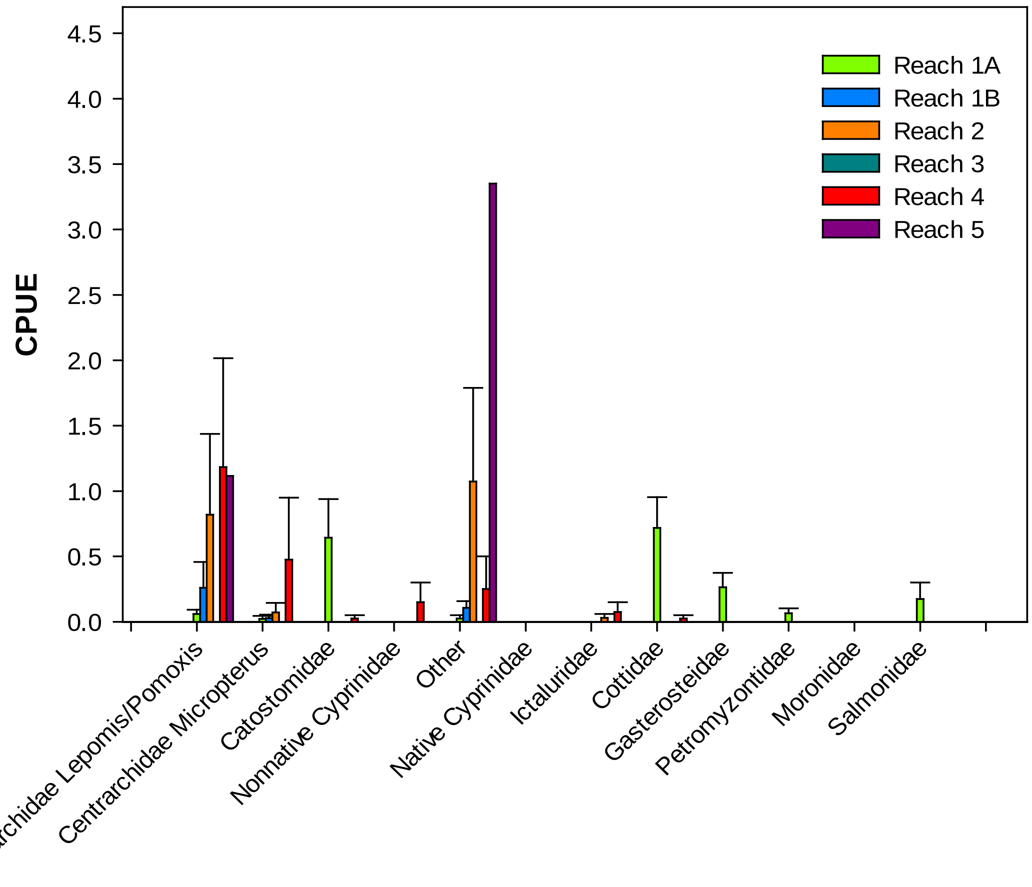


Figure 18.—Catch-per-unit-effort (CPUE; fish/minute shock time) during backpack electrofishing October 2012. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

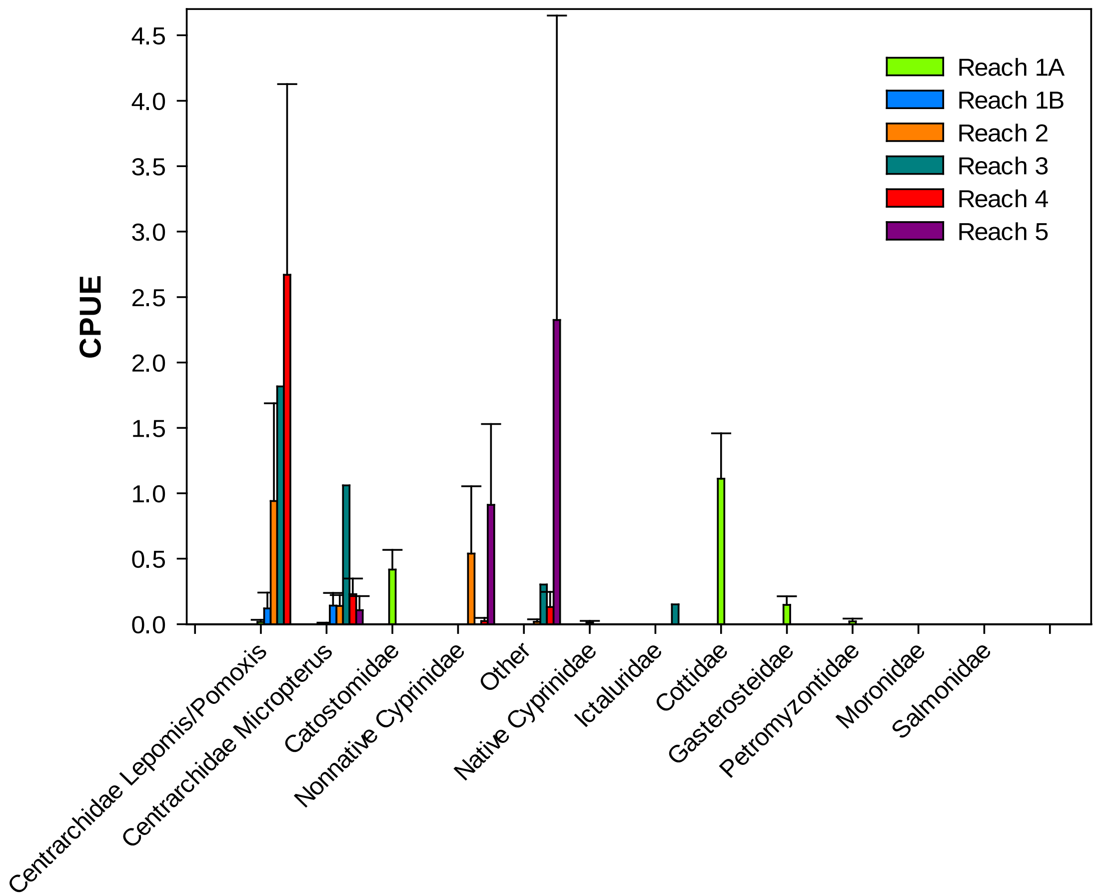


Figure 19.—Catch-per-unit-effort (CPUE; fish/minute shock time) during backpack electrofishing January 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

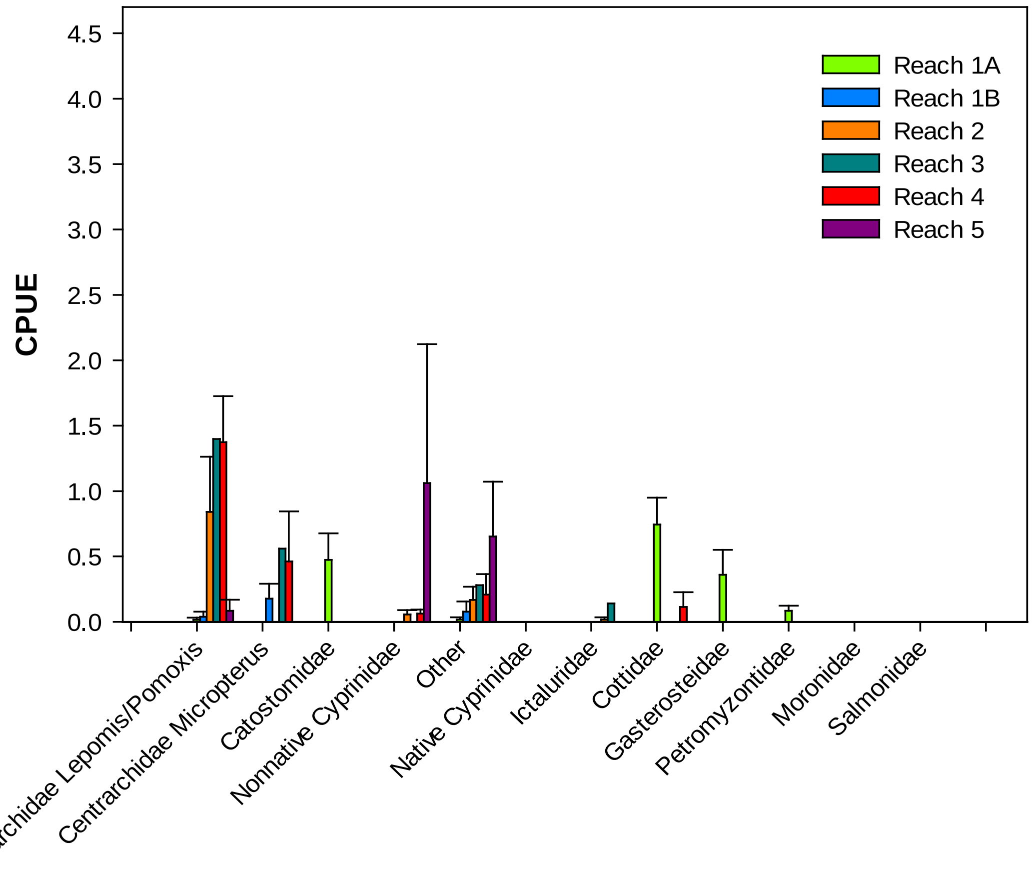


Figure 20.—Catch-per-unit-effort (CPUE; fish/minute shock time) during backpack electrofishing March/April 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

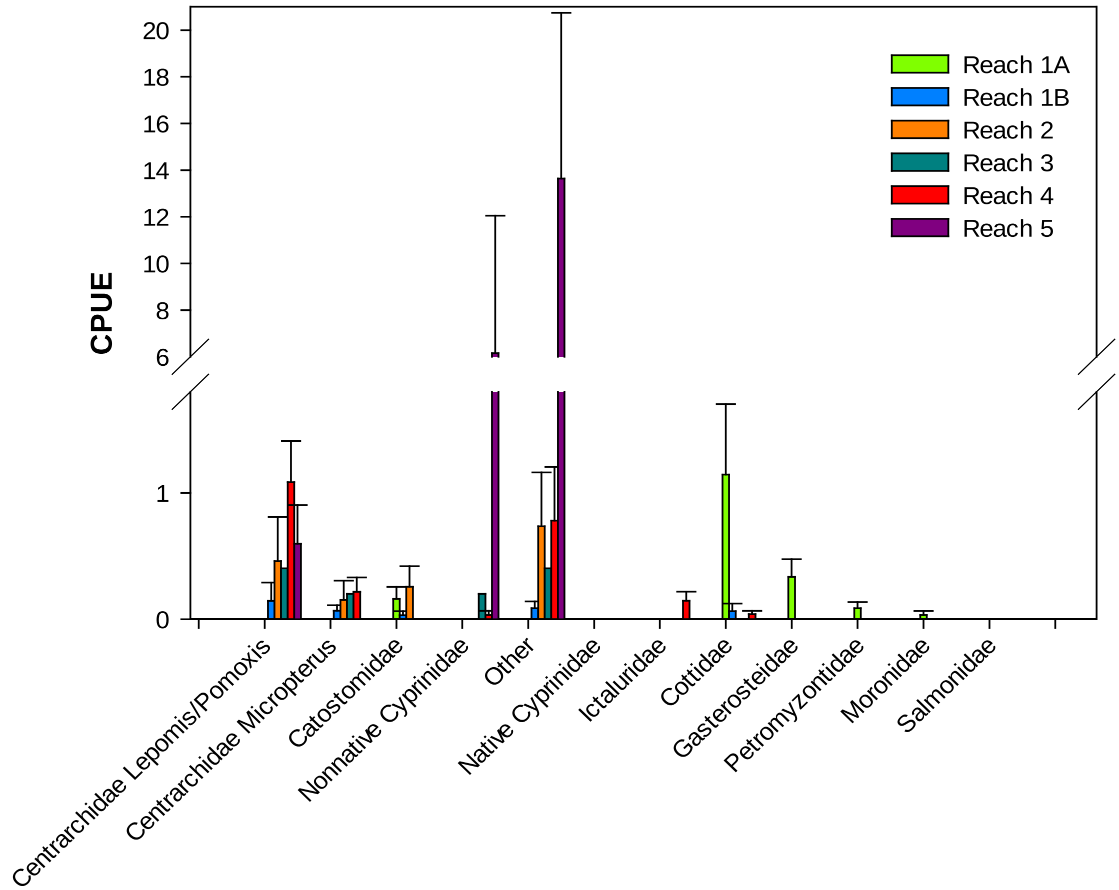


Figure 21.—Catch-per-unit-effort (CPUE; fish/min shock time) during backpack electrofishing June 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach. Note the scale break on the y-axis.

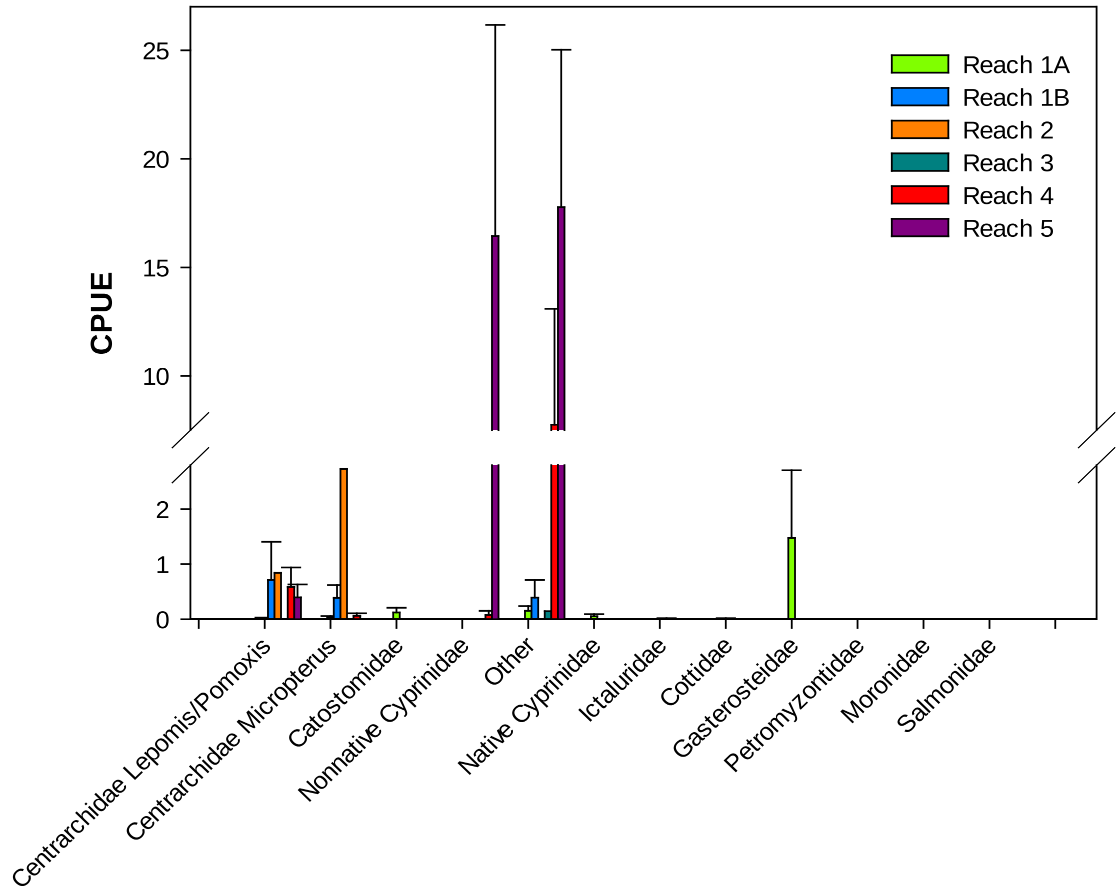


Figure 22.—Catch-per-unit-effort (CPUE; fish/m[3]) during seining October 2012. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach. Note the scale break on the y-axis.

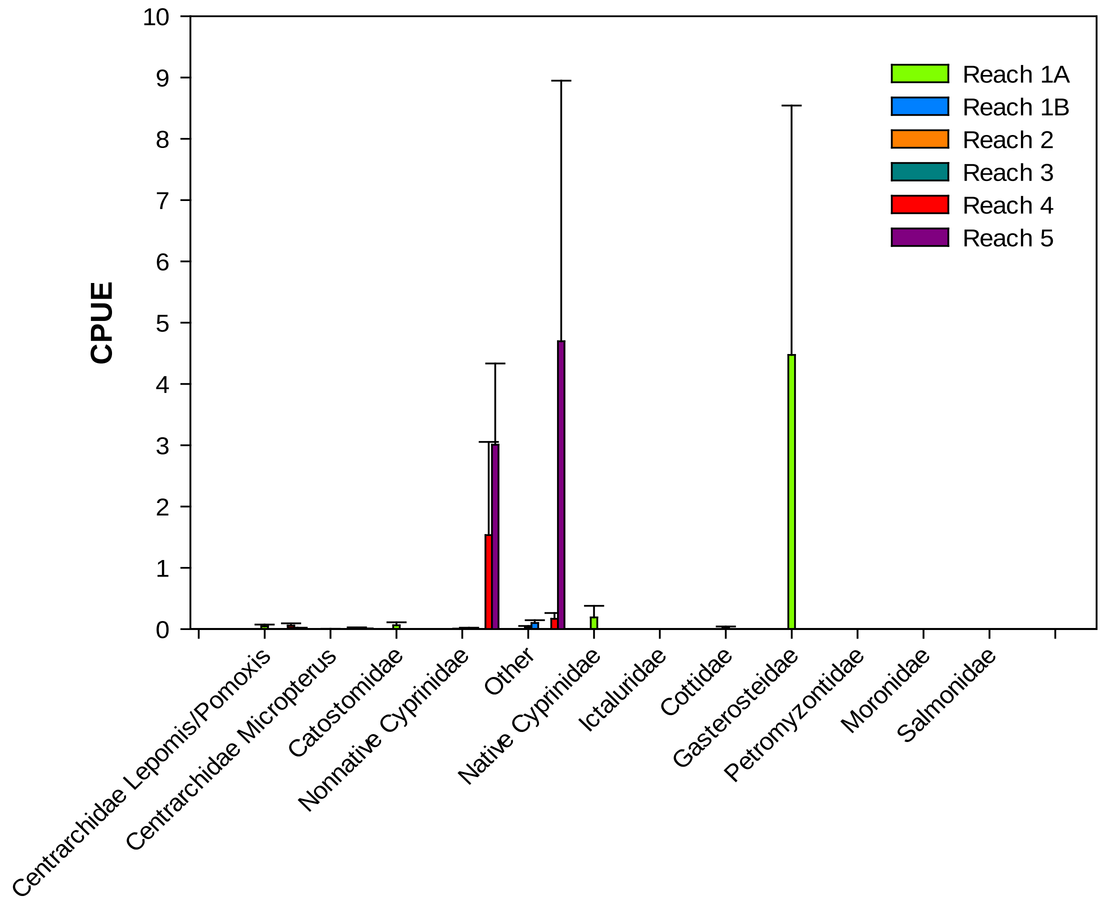


Figure 23.—Catch-per-unit-effort (CPUE; fish/m^3) during seining January 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

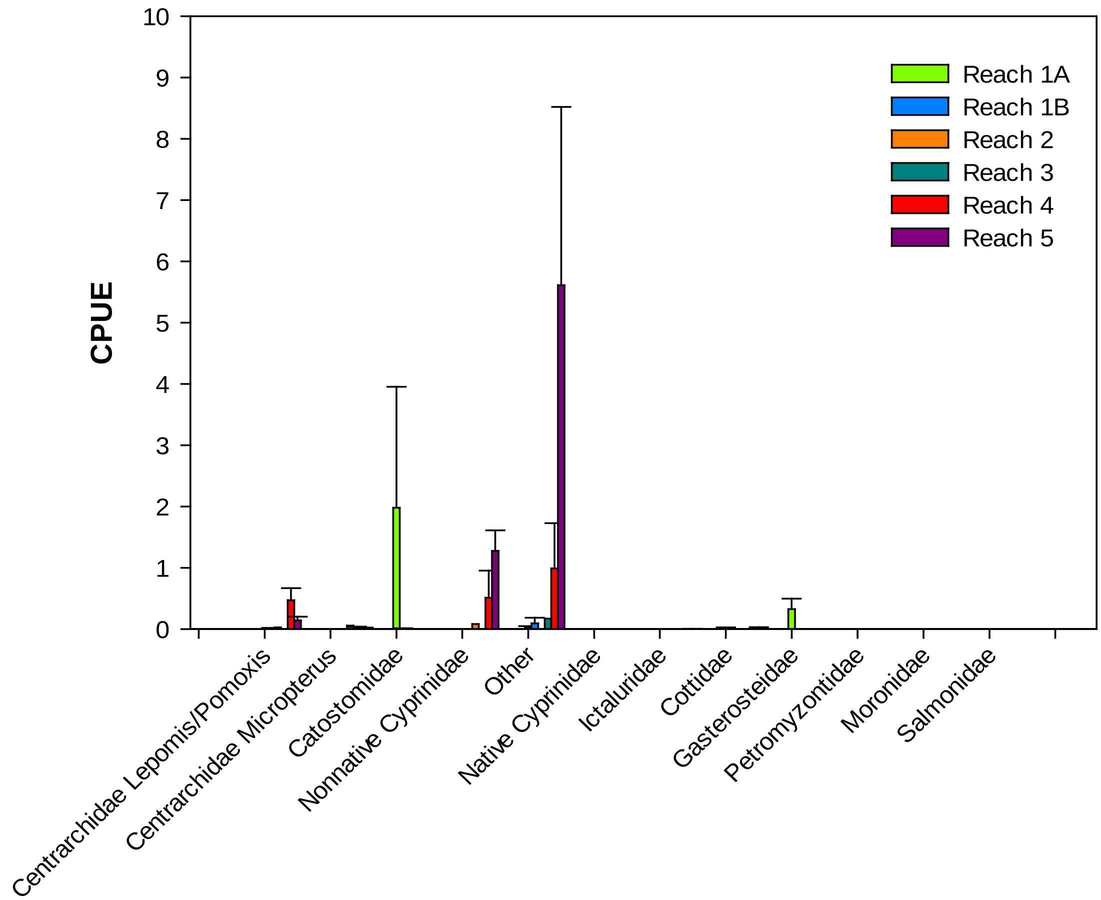


Figure 24.—Catch-per-unit-effort (CPUE; fish/m^3) during seining March/April 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach.

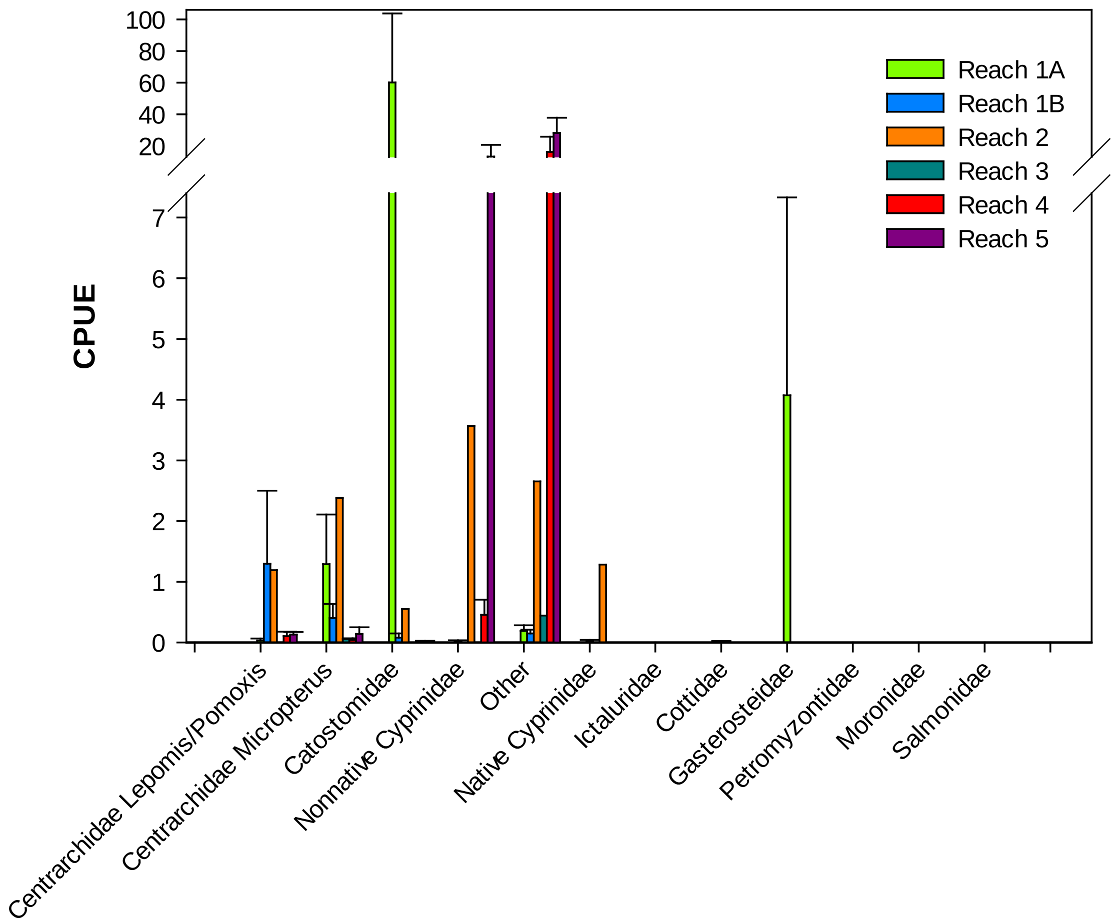


Figure 25.—Catch-per-unit-effort (CPUE; fish/m^3) during seining June 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach. Note the scale break on the y-axis.

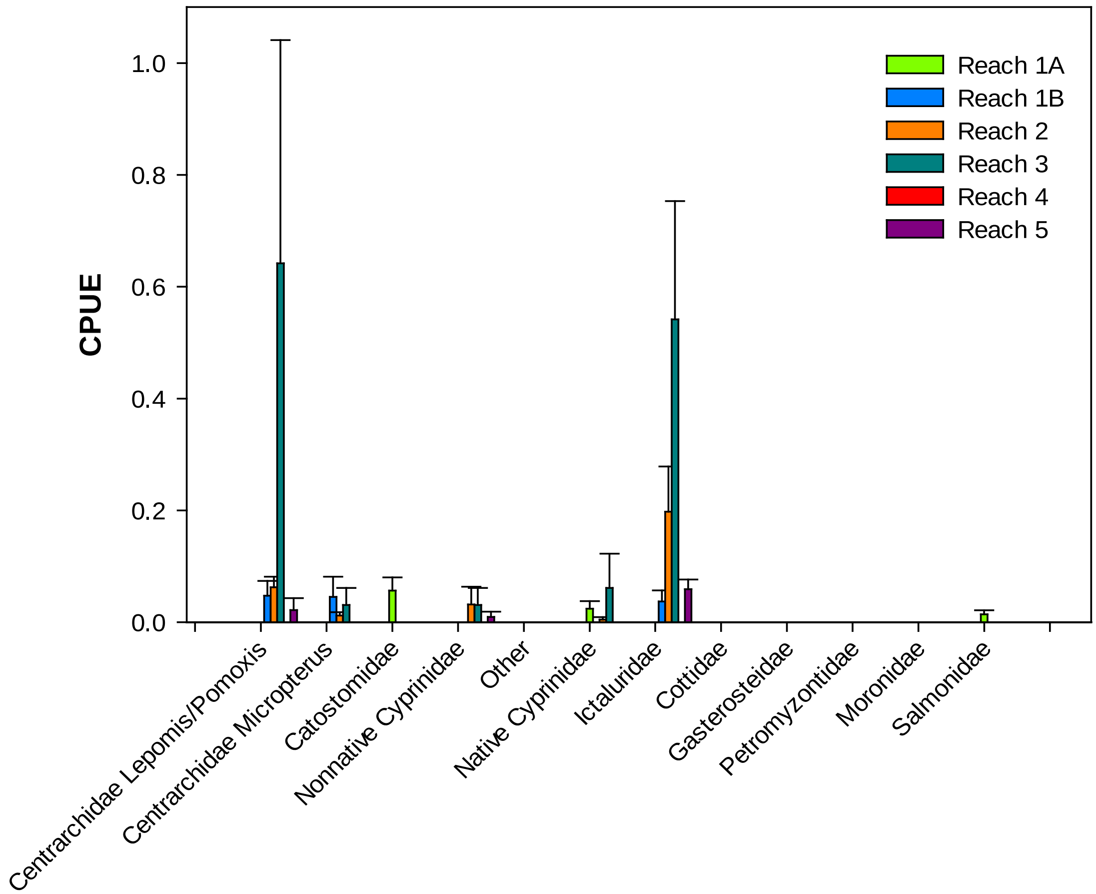


Figure 26.—Catch-per-unit-effort (CPUE; fish/m^2/day) during trammel netting October 2012. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE.

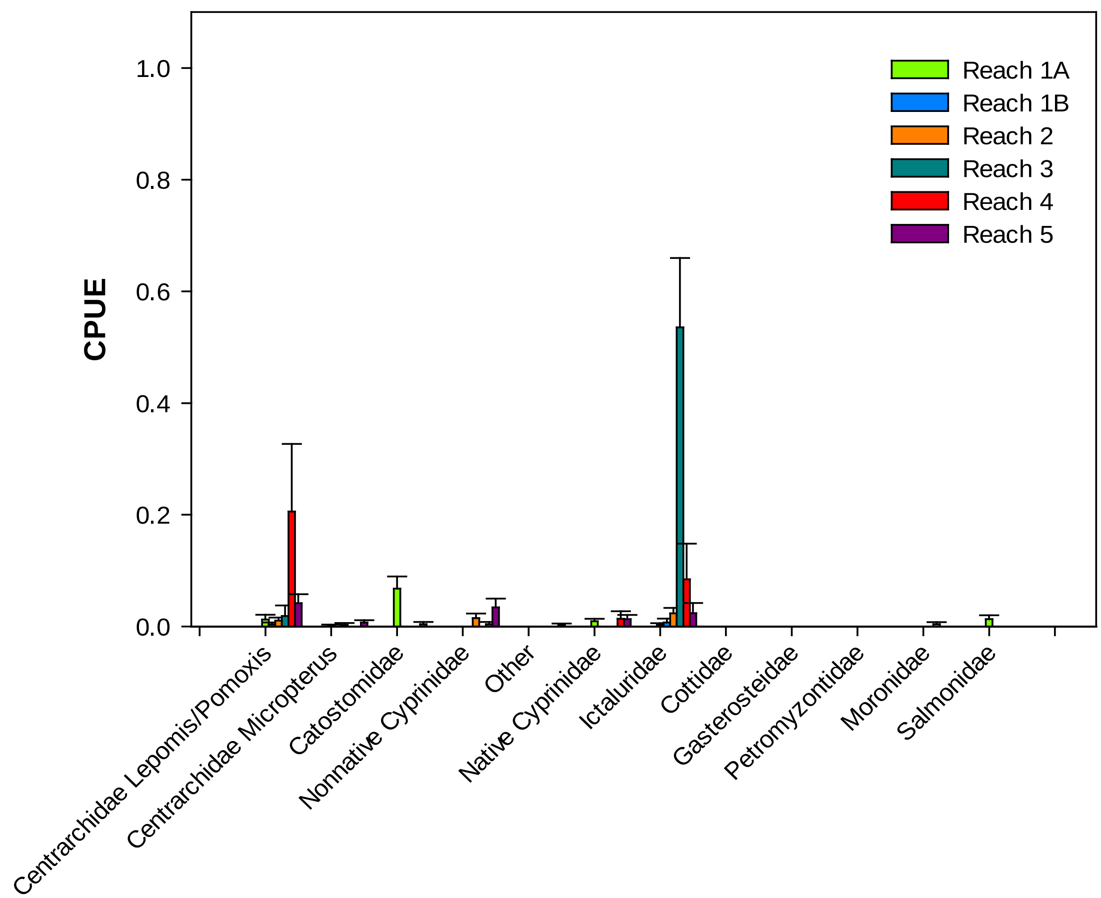


Figure 27.—Catch-per-unit-effort (CPUE; fish/m^2/day) during trammel netting January 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE.

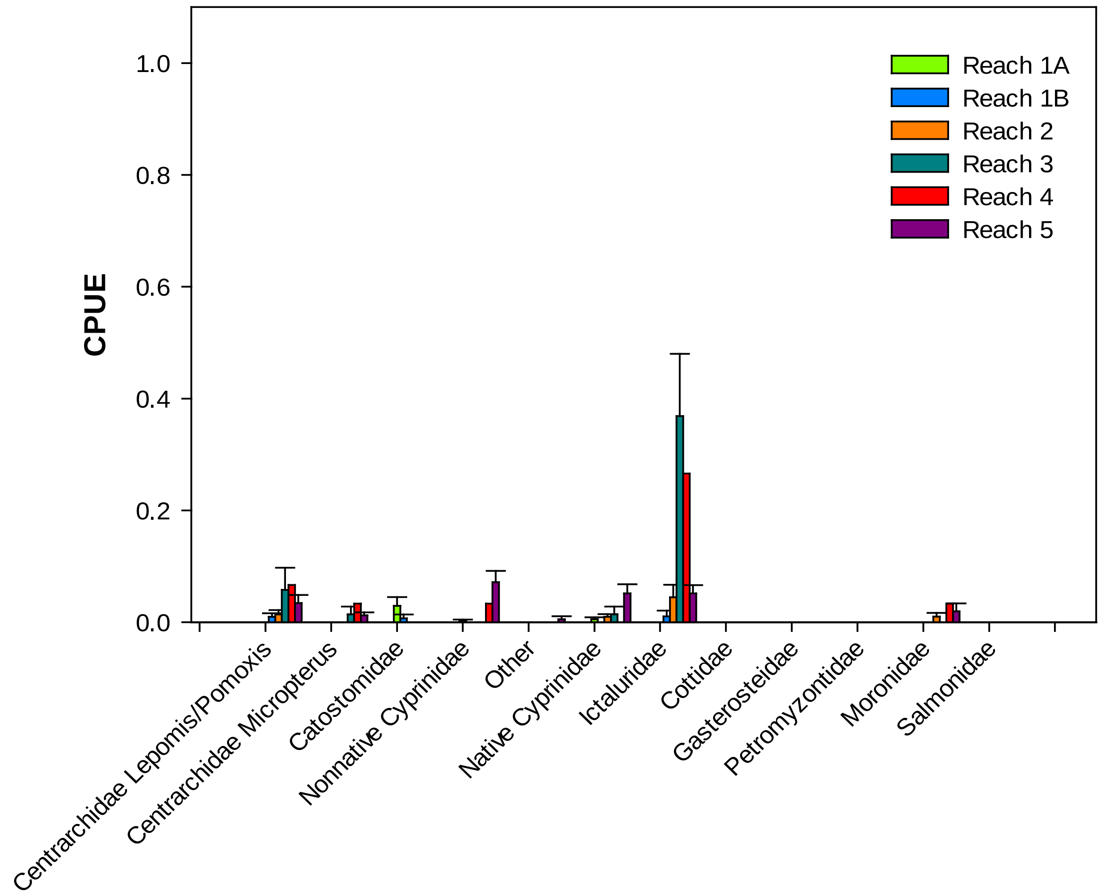


Figure 28.—Catch-per-unit-effort (CPUE; fish/m^2/day) during trammel netting March/April 2013. CPUE presented by Restoration Reach and fish category. “Other” category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE. Reaches without SE bars indicate only one sample site in that particular Reach. Reaches without SE bars indicate only one sample site in that particular Reach.

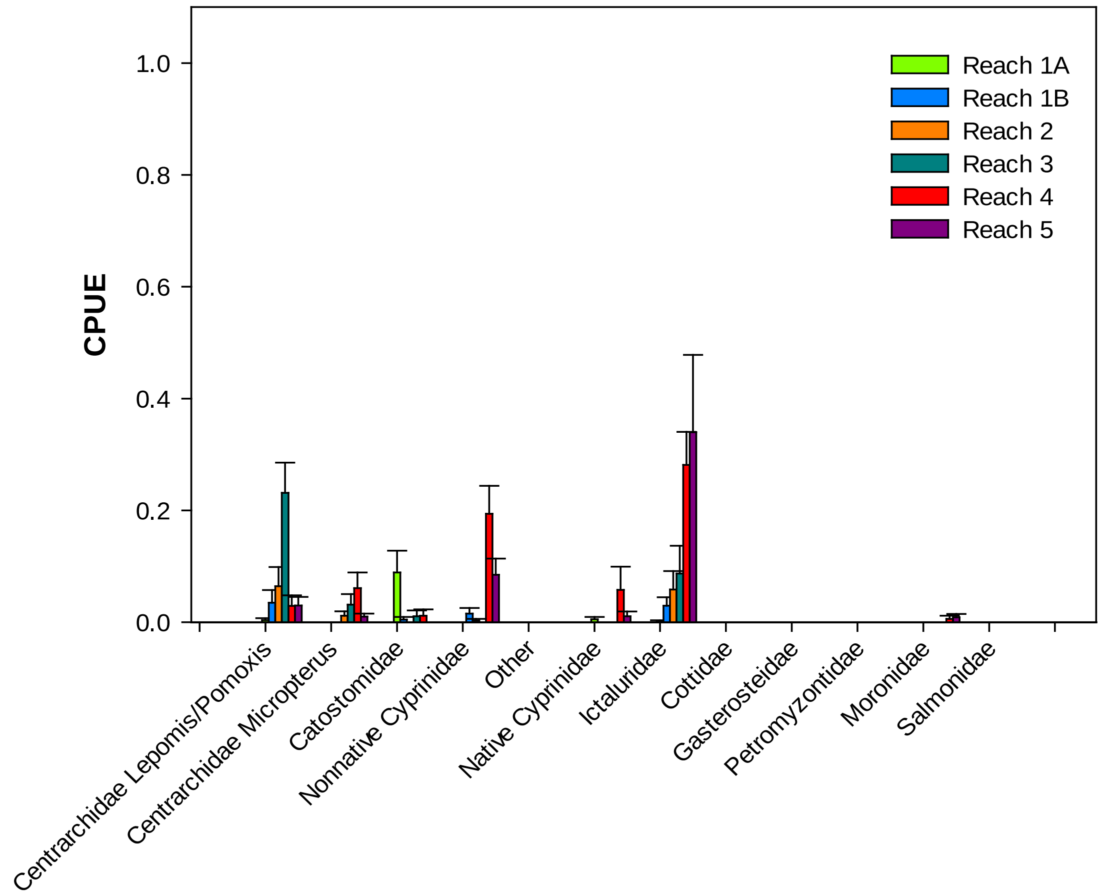


Figure 29.—Catch-per-unit-effort (CPUE; fish/m²/day) during trammel netting June 2013. CPUE presented by Restoration Reach and fish category. "Other" category includes species in Atherinopsidae, Clupeidae, Gobiidae, Percidae, and Poeciliidae. Error bar represents +1 SE.

and reduce entrainment (SJRRP 2011; SJRRP 2012). This will lead to complete changes in habitat and river function in those areas. All these areas will be monitored to that fish populations are maintained in good health as the restoration process continues. Currently, across sampling methods, sample sites are well-spaced in Reach 1, 2, 4B2, and 5. More seining and backpack electrofishing in Reach 3 and the upper parts of Reach 4 would be helpful to monitor the fish community in those areas, particularly as construction projects move forward and flows increase.

As a future metric, the relative abundance of species within an assemblage can be combined into a measure that is intended to describe the state of the community. Fish are especially suited to indicate environmental quality. Using fish as an indicator is simple and can be applied without intensive data analysis. The application is more biologically relevant when indicator guilds are used, because they may imply ecological function (Guy 2007). A common method for classifying North American fishes is general feeding guild categorizations based on proportions of diet (Karr *et al.* 1986; Mathews 1998). General categories include invertivore, piscivore, herbivore, omnivores, and planktivore (Karr *et al.* 1986). Fish recovered from I&M efforts will be separated into these feeding guilds based on diet preferences listed in current literature. The relative abundance of these guilds will be monitored as the restoration continues to see if the ecological function of the river reaches change. This will allow inferences to be made about how the ecology of the river is changing in response to restoration efforts.

By collecting baseline data, we are establishing a prescience of attributes that can be quantitatively and semi-quantitatively measured against successive sampling to detect possible changes in fish community structure. Native fish are generally more restricted in distribution that nonnative fish, in the Restoration Area (see table 5). Furthermore, CPUE is lower, in most cases, for native fish than nonnative fish (figures 14 – 29). Detecting future changes in CPUE, though, may prove difficult because of the uncertainty of current results (*i.e.*, large standard error of CPUE results). Although the standard error may decrease with increased efforts, future efforts should focus on refining current methods to best detect these changes (*e.g.*, increasing sample sites in Reaches that are under-represented) and/or incorporating additional methods under the adaptive management plan for monitoring which could provide information to detect changes in fish distribution. However, increasing sampling to levels needed to detect these changes may prove impractical under current monitoring plans (Paukert 2004). Because of the limited distribution of native fish within the Restoration Area, the increasing presence of native fish in additional reaches could be used to realize improvements in fish populations, assuming early stages of population expansion are detectable under current sampling methods (Bayley and Peterson 2001). Other methods of monitoring changes in target species' populations should be considered; for example, mark-recapture studies could be used to determine population parametrics (*e.g.*, abundance, survival, recruitment; Pradel 1996), or correspondence analysis could be used to predict species' distribution relative to environmental variables in the Restoration Area (Paukert 2004; Marichetti and Moyle 2001). While current CPUE data may have its limitations, data presented in this study will nonetheless provide a foundation for future efforts and can be incorporated into future monitoring efforts (Maunder 2006).

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APPENDIX A

River Sensors

Table A-1.—River sensors and associated information used to provide flow data during raft electrofishing sampling periods. USGS = U.S. Geological Survey; DWR = California Department of Water Resources, Reclamation = Bureau of Reclamation

Station	Description	Operator	Latitude	Longitude	River Mile	Oct Float	Jan Float	Mar/Apr Float	Jun Float
SJF	SJR below Friant Dam	USGS	36.984394	119.724312	266.0	10/09/12	01/08/13	03/26/13	06/04/13
H41	SJR at Hwy 41 Bridge	Reclamation	36.876200	119.793200	255.1	10/10/12	01/09/13	03/27/13	06/04/13
DNB	SJR at Donny Bridge	Reclamation	36.833500	119.965800	240.7	10/11/12	01/10/13	03/28/13	06/05/13
SKB	SJR at Skaggs Bridge (Hwy 145)	Reclamation	36.822900	120.088400	232.1	10/11/12	01/12/13	03/29/13	06/06/13
GRF	SJR at Gravelly Ford	Reclamation	36.798000	120.160000	227.5	10/11/12	01/12/13	03/29/13	06/06/13
SJB	SJR below Bifurcation	Reclamation	36.773000	120.286000	215.9	10/12/12	01/11/13	03/29/13	06/07/13
SJN	SJR at San Mateo Rd	USGS	36.778889	120.306664	212.2	10/12/12	01/11/13	03/29/13	06/07/13
MEN	SJR near Mendota	USGS	36.810505	120.378227	202.1	10/13/12	01/13/13	03/30/13	06/07/13
SDP	SJR near Dos Palos	DWR	36.994000	120.501500	181.2	10/14/12	01/14/13	04/01/13	06/08/13
SWA	SJR at NR Washington Rd	DWR	37.115320	120.587000	168.4	10/14/12	01/14/13	04/01/13	06/08/13
SJS	SJR near Stevinson	DWR	37.295000	120.851000	132.8	10/04/12	01/14/13	03/31/13	06/09/13
FFB	SJR at Freemont Ford Bridge	USGS	37.309940	120.931038	125.1	10/03/13	01/15/13	03/31/13	06/08/13
NEW	SJR above Merced near Newman	USGS & DWR	37.350494	120.977150	118.1	10/03/12	01/15/13	04/01/13	06/08/13

Table A-2.—River sensors and associated information used to provide dissolved oxygen data during raft electrofishing sampling periods. DWR = California Department of Water Resources, Reclamation = Bureau of Reclamation

Station	Description	Operator	Latitude	Longitude	River Mile	Oct Float	Jan Float	Mar/Apr Float	Jun Float
FWQ	SJR at Friant Dam	Reclamation	36.999300	119.706100	267.5	10/09/12	01/08/13	03/26/13	06/04/13
GRF	SJR at Gravelly Ford	Reclamation	36.798000	120.160000	227.5	10/11/12	01/12/13	03/29/13	06/06/13
SJB	SJR below bifurcation	Reclamation	36.773000	120.286000	215.9	10/12/12	01/11/13	03/29/13	06/07/13
SDP	SJR near Dos Palos	CADWR	36.994000	120.501500	181.2	10/14/12	01/14/13	04/01/13	06/08/13
SWA	SJR near Washington Road	CADWR	37.115320	120.587000	168.4	10/14/12	01/14/13	04/01/13	06/08/13
SJS	SJR near Stevinson	CADWR	37.295000	120.851000	132.8	10/04/12	01/14/13	03/31/13	06/09/13