Big Chico Creek

2014 Fish Population Survey

Prepared By:
Dana Lee
Michael Hellmair
Matt Peterson

FISHBIO
1617 S. Yosemite Ave.
Oakdale, CA 95361
209.847.6300
www.fishbio.com

February 2015

Table of Contents

Introduction **2**

Methods **5**
Study Site 5
Habitat Mapping and Unit Selection 6
Dive Counts 7
Fish Abundance 8

Results **11**
Habitat Mapping and Unit Selection 11
Fish Abundance 11
Stream Characteristics 14

Discussion **17**

Acknowledgements **20**

Bibliography **21**

Introduction

Steelhead, the anadromous life history form of rainbow trout (*Oncorhynchus mykiss*), were once abundant throughout rivers in California's Central Valley (CV). A combination of anthropogenic factors has resulted in severely reduced abundance of these ocean-going trout, including dam construction, mining, and logging. In addition, modification of creeks and rivers for navigation and flood protection has reduced and degraded available spawning and rearing habitat (McEwan 2001). As a consequence, steelhead have become relatively rare in the Central Valley, prompting their listing as "Threatened" under the Endangered Species Act (ESA) in 1998, a status that was reaffirmed in 2006.

Though this listing has afforded the species special protection and made resources available to facilitate its recovery, management of steelhead is challenged by the complex life history of the species (Satterthwaite et al., 2010). Most populations of *O. mykiss* in anadromous watersheds are partially migratory: some individuals emigrate to the ocean where they grow to adulthood before returning to freshwater habitats to reproduce, while others remain in their natal riverine habitat and reach maturity without undergoing long-distance migrations. For anadromous individuals (steelhead), the food-rich marine environment offers the potential for higher growth, larger size, and higher fecundity. However, migration to the ocean and the typically later age at maturity of these individuals reduce their probability of surviving until reproduction (Fleming and Reynolds 2004). Resident rainbow trout typically mature at a younger age and smaller size, and they have a higher chance of surviving until reproduction, as well as a higher rate of iteroparity (repeat spawning; Fleming and Reynolds 2004, Schill et al. 2010).

Further challenges for fisheries management stem from considerable plasticity within life-history types. For example, individuals that migrate to sea can do so at various ages, and some may migrate out to the Sacramento-San Joaquin estuary or San Francisco Bay and return to spawn without spending any time in the open ocean (Teo et al. 2011, Null et al. 2012). Additionally, in some and maybe all rivers where steelhead and rainbow trout are sympatric, migratory and resident forms interbreed and may produce offspring with a life history different from their own (Zimmerman and Reeves 2000, Heath et al. 2008, Zimmerman et al. 2009, Christie et al. 2011, Courter et al. 2013). These examples illustrate why assessing steelhead population viability in the region is difficult.

Management of steelhead depends on the prevalence of the migratory polymorphism in a population. Within the CV Evolutionary Significant Unit (ESU), it may not be possible to manage one life-history morph without reference to the other (Williams et al. 2007). Without information regarding the abundance of *O. mykiss* or the prevalence of various life-history morphs, it is difficult to examine how changes in the environment may affect the population abundance as a whole. Consistent and robust population monitoring is necessary to document trends and natural variation in *O. mykiss* abundance and to understand whether certain actions may negatively or positively affect population size (Eilers et al. 2010). While the life history plasticity of *O. mykiss* raises substantial challenges for management and recovery of the anadromous population segment, it underlines the importance of including resident rainbow trout in status assessment and recovery planning of anadromous steelhead.

While comprehensive monitoring plans are in place to track and assess most larger remaining populations of other anadromous salmonids (typically Chinook salmon, *Oncorhynchus tshawytscha*), nearly all of the 81 historical populations of steelhead in the CV are considered data deficient (Lindley et al. 2006, Lindley et al. 2007, National Marine Fisheries Service 2009). Despite, or perhaps as a result of, management focus on anadromous salmonids, other native species are often only given ancillary consideration in assessment of fish populations in California. However, it has been apparent for decades that the decline of native fish fauna in lotic waters of inland California has been paralleling that of Central Valley steelhead (Moyle and Nichols 1974, Moyle and Williams 1990). To alleviate data deficiencies associated with abundance of *O. mykiss* and to track the distribution and demographic characteristics of other native species, the study of smaller watersheds that remain relatively undeveloped is of great importance. The study of these systems can help provide insights regarding large-scale population trends and patterns that may be masked by the effects of localized changes in riverine conditions resulting from infrastructure developments (i.e., dam construction and operation).

Big Chico Creek is well suited for such an assessment as it supports populations of both steelhead and resident rainbow trout in the 24 miles of the stream accessible to anadromous fish (USFWS AFRP; Figure 1). Large water storage infrastructures do not exist on Big Chico Creek, and a natural barrier (Higgin's Hole) blocks the upstream migration of anadromous fish species. Past efforts to enhance the salmonid populations in Big Chico Creek have included a rotenone treatment (a piscicide) by the California Department of Fish and Wildlife (CDFW; then California Department of Fish and Game), applied in 1986 between Higgin's Hole and Iron Canyon in response to perceived competition from non-game fish on salmonids. This treatment was followed by the release of large numbers of hatchery-reared Chinook salmon and steelhead fry over the course of several years. Following the toxic treatment, Dr. Paul Maslin (California State University, Chico) and his students conducted annual surveys in the affected reach from 1986 to 1998. The overall effectiveness of the rotenone treatment for restoring anadromous fish populations remains unclear. While populations of rainbow trout generally increased slightly over the study period, this may be attributable to the large stocking efforts and stochastic weather events (i.e., winter flooding) rather than the result of reduced competition/predation by native species (Maslin 1997a). Native non-game fishes were extremely slow to re-colonize the affected area of the creek, and only California roach (*Lavinia symmetricus*) were observed at high abundances after the treatment (Maslin 1997a). Riffle sculpin (*Cottus gulosus*) later rebounded close to pre-treatment levels, with considerable recruitment being observed after the 1997 flood events (Maslin 1997a).

To address the increasingly recognized need to incorporate the resident rainbow trout populations in status assessment and management of the steelhead CV ESU, and to assess the demography and distribution of native fish species in the upper anadromous reaches of Big Chico Creek, we conducted quantitative assessments of Big Chico Creek fish populations in the summers of 2013 and 2014. The survey in 2014 covered the full extent of over-summering habitat in the watershed accessible to anadromous species. Abundance estimates reported herein are based on direct observation dive counts (i.e., snorkel surveys). This is a cost-effective, non-invasive method of estimating abundance based on visual counts. It does not require fish handling and can provide counts similar to depletion electrofishing under conditions such as those found on Big Chico Creek during the summer months (Mullner et al. 1998, Allen and Gast 2007).

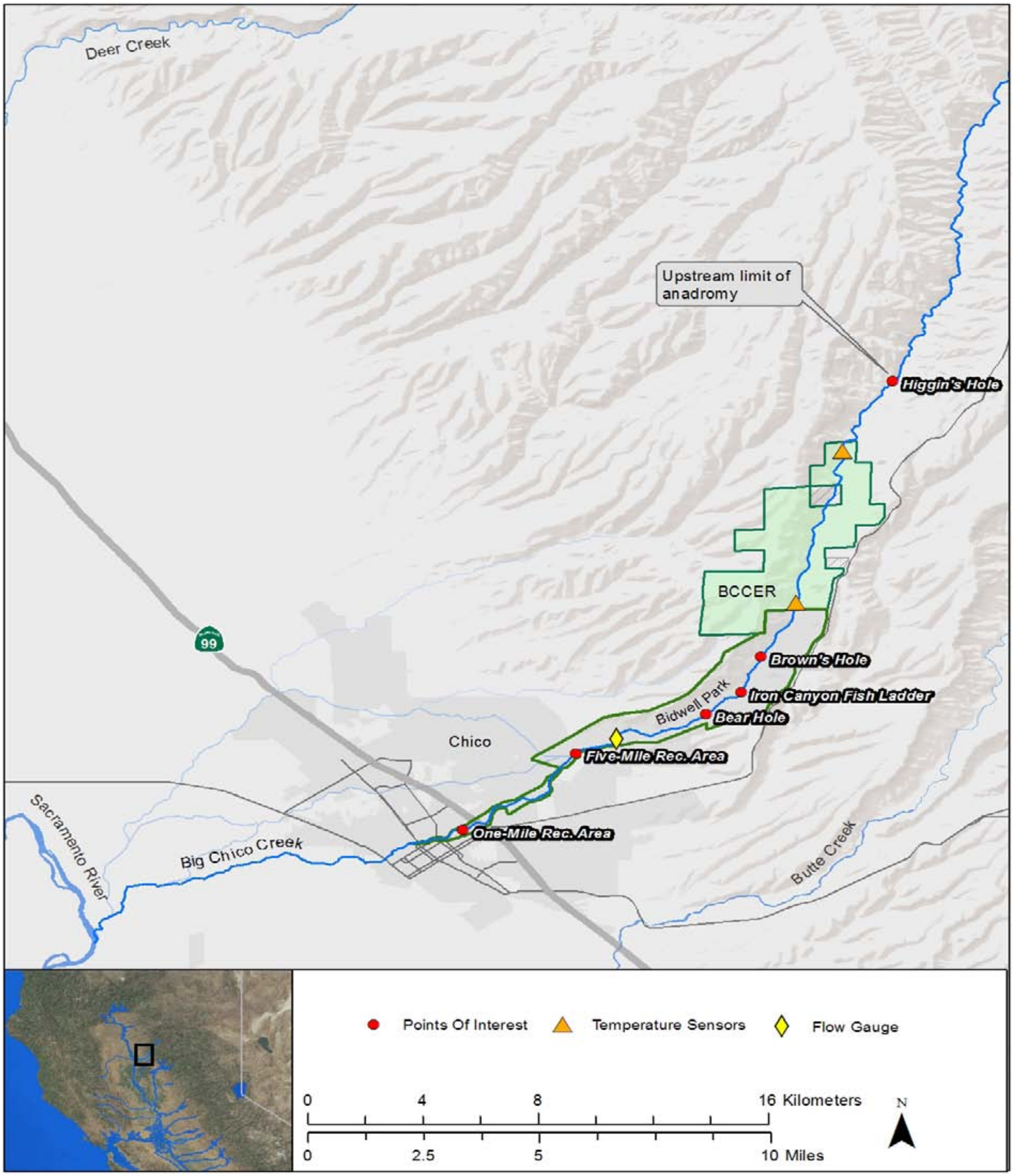

Figure 1. Map of the Big Chico Creek watershed.

Material and Methods

Study Site

Big Chico Creek originates on the western slope of Colby Mountain, at an elevation of 5,400 feet, and flows 45 miles to its confluence with the Sacramento River. It is one of several small eastside tributaries to the Sacramento River (along with Butte Creek, Deer Creek, Mill Creek and Antelope Creek) that have comparable topography and annual discharge patterns. All of these creeks flow into the Sacramento River within approximately 40 miles of one another, are mostly undammed, and are all considered high-priority watersheds for conservation and restoration of anadromous fish populations.

Big Chico Creek can be roughly divided into three different zones, based on both geological barriers and the composition of the fish community: valley zone, foothill zone, and mountain zone.

The valley zone is the lowermost zone in the watershed, and extends from the confluence with the Sacramento River upstream to Iron Canyon, located in Upper Bidwell Park (Figure 1). In this narrow canyon, as the creek flows over a geologic formation known as the Lovejoy basalt, years of erosion have resulted in an assemblage of large basalt boulders in the middle of the creek. The arrangement of these boulders has formed impassable barriers to anadromous fish during normal flows, but during high flows, upstream migration past Iron Canyon is possible (DWR 2002). The fish community in the valley zone is dominated by introduced centrarchids (black bass and sunfishes, *Micropterus spp*. and *Lepomis spp*., respectively), native Sacramento pikeminnow (*Ptychocheilus grandis*), hardhead (*Mylopharodon conocephalus*), and Sacramento sucker (*Catostomus occidentalis*). The valley zone does not provide much suitable spawning habitat for salmonids, has larger populations of predatory fish, and experiences seasonally high water temperatures in excess of the physiological tolerance of salmonids (BCCWA 1997).

The foothill zone extends upstream from Iron Canyon and ends at Higgin's Hole, where a large waterfall forms the upstream barrier to anadromous fish migration on Big Chico Creek (though it may be possible for spring-run salmon and steelhead to navigate past this waterfall during rare, unusually wet years). The timing of high flows and fish migrations have a significant effect on the accessibility of the foothill zone to various fish species. Although a fish ladder was built in Iron Canyon to permit more frequent access to this upstream area in the 1950s, years of deterioration in absence of maintenance have rendered it ineffective. Steelhead, migrating between November and February, can typically navigate the partial barrier in Iron Canyon. Other species, such as spring- and fall-run Chinook salmon (with different migration times), often have difficulty accessing this section of the creek (DWR 2002). Historically, anadromous fishes dominated the foothill zone, and Chinook salmon, steelhead, and Pacific lamprey (*Lampetra tridentata*) were prominent in this reach. Populations of native cyprinids, including hardhead, Sacramento pikeminnow, and California roach (*Lavinia symmetricus*), as well as brown trout (*Salmon trutta*), Sacramento sucker, and riffle sculpin were also found in the foothill zone (Maslin 1997a, BCCWA 1997). It is unclear whether the resident species can migrate upstream through Iron Canyon; however, the apparent lack of recolonization of the foothill zone following the rotenone treatment suggests that these resident species have difficulty accessing this area from the valley zone. No hardhead and only two Sacramento pikeminnow were observed in the study area after the treatment, though limited numbers of Sacramento suckers were documented after the treatment (all less than 300mm in length; Maslin 1997a). Between 1987 and 1991, over 1.5 million Chinook salmon fry and several hundred thousand steelhead fry (Feather River stock) were planted in the foothill zone (just below Higgin's Hole) to bolster populations of these species following the piscicide treatment (BCCWA 1997).

The mountain zone extends from Higgin's Hole upstream to the headwaters of Big Chico Creek and only supports resident rainbow and brown trout. In the small headwaters where tributaries are spring-fed and most precipitation falls as snow, winter flooding is not severe. This is thought to favor the reproductive success of exotic brown trout over native rainbow trout, and brown trout have come to dominate the uppermost reaches of the Big Chico Creek watershed and are typically the only fish species found in this area (Maslin 1997b).

The Big Chico Creek Ecological Reserve, a 3,950-acre parcel of land which encompasses an estimated four and a half miles of Big Chico Creek, is located in the foothill zone about two miles downstream of Higgin's Hole (Figure 1). The BCCER, along with the two-mile long reach between the upstream Reserve boundary and Higgin's Hole, was chosen as the location for this survey as it provides accessible habitat along a relatively large section of the creek located directly below the barrier to anadromy. This portion of Big Chico Creek likely provides the highest quality habitat for anadromous fish in the watershed.

Habitat Mapping and Unit Selection

In order to obtain an accurate estimate of fish abundance, the entire reach of Big Chico Creek between the downstream barrier of the BCCER and Higgin's Hole was surveyed on foot and categorized into habitat units based on a four-category classification (i.e., riffle, run, pool, and cascade). Global Positioning Satellite (GPS) waypoints were taken at the boundaries of each habitat unit using a hand-held Garmin® GPS unit (Garmin International Inc., Olathe, KS) in order to accurately locate each habitat unit during subsequent surveys. In addition, the length and width of each unit was measured with a Bushnell® rangefinder (Bushnell Outdoor Products, Overland Park, KS), and the maximum water depth of each unit was determined with a stadia rod. Other measurements recorded during habitat mapping included water temperature (at the downstream end of each unit), dominant substrate, dominant cover, and presence of large woody debris. Units that appeared to pose potential hazards to snorkelers or were otherwise unsuitable for the proposed survey type were identified. Stream sections classified as "cascades" are often hazardous or do not permit sufficient visual coverage due to turbulence, and were excluded from this survey.

Within each habitat stratum conducive to visual surveys (run, riffle, pool), units were sampled systematically by generating a random number between 1 and 5, and subsequently surveying every k^{th} unit in an upstream direction. Depending on habitat type, approximately one fifth of all the units were surveyed (see Table 1). A sub-sample of the surveyed units was randomly selected for calibration of dive counts, using the Method of Bounded Counts (MBC), as described in more detail below.

Dive Counts

There are many methods for estimating the total abundance of fish in freshwater systems, the majority of which depend on handling the fish during enumeration (e.g., electrofishing, seining etc.). Direct observation dive counts (i.e., snorkel surveys) are an efficient, non-invasive means of estimating abundance based on visual counts, which do not require fish handling (Allen and Gast 2007). Therefore, this method is preferred for listed species and species of special concern. In some situations, when water visibility is excellent and conditions are good, snorkeling can provide counts similar to depletion electrofishing (Mullner et al. 1998). However, visual estimates are typically negatively biased since certain factors can affect fish detectability (e.g., visibility, temperature, time of day, species-specific behaviors and fish size) (Northcote and Wilkie 1963 as cited by Hagen and Baxter 2005, Mullner et al. 1998, Bradford and Higgins 2001, Hagen and Baxter 2005, O'Neal 2007, Hagen et al. 2010). Therefore, without estimates of observer bias (which generally require depletion estimates of abundance for a subsample of the reaches under study), single-pass snorkel surveys cannot provide an estimate of absolute abundance. Rather, they provide an unbiased index of abundance with associated confidence intervals. A viable alternative to obtaining accurate population size estimates by traditional methods (such as depletion electrofishing or mark-resighting experiments) is the Method of Bounded Counts. This approach relies on repeated counts of fish from the same unit (generally four passes) and produces nearly unbiased estimates of abundance if fish abundance in respective survey units is relatively low (Mohr and Hankin 2005). As such, this method provides a non-invasive (no fish handling required) alternative to traditional methods that is highly applicable to stream surveys involving species of special concern.

Snorkel surveys were conducted on July 21-25, 2014. A standardized protocol was followed to ensure comparability of survey results over subsequent years and to minimize variation due to sampling error. The number of divers needed for a snorkel survey was dependent on the width of the stream, but was selected to ensure complete visual coverage of the stream during upstream snorkeling. If the stream section to be surveyed required more than two divers for complete visual coverage of the stream width, parallel dive lanes were established prior to snorkeling. Dive lanes were assigned randomly to divers at each survey unit to minimize the effects of diver familiarity with the physical habitat and fish population on dive counts. Care was taken to minimize disturbance of fish prior to sampling each unit.

Divers entered the stream at the downstream border of the survey reach and counted fish within their respective dive lanes as they proceeded upstream in unison with the other divers. Divers recorded fish counts on a wrist-mounted dive slate and assigned a size category to each observation (less than 150 mm, 150-300 mm, and greater than 300 mm). Divers were equipped with two reference dowels (150 mm and 300 mm in length) to facilitate the correct estimation of fish size and account for underwater size distortion. When approaching the upstream boundary of the survey unit, divers carefully monitored fish holding close to the unit boundary and included fish that crossed the unit boundary in an upstream direction. Any fish that was observed moving between lanes was noted immediately after the dive to avoid multiple counts of the same fish. To minimize potential observer bias during all snorkel passes, the units selected for additional passes were not revealed to the divers until the first dive pass was completed. In sampling units that were selected for calibration of single-pass dive counts, a minimum of five minutes was allowed to elapse between each of the three subsequent dives.

Obtaining accurate counts of *O. mykiss* and *S. trutta* was the priority of this survey. Other observed species (and their lengths) were recorded, so long as this did not compromise counts of the focal species.

Fish Abundance

To estimate total abundance of focal fish species, a two-phase estimator was used in each stratum surveyed (runs, riffles, and pools) to "calibrate" single-pass counts. Error in abundance estimation can occur in the first and second phase of estimation, termed sampling error and measurement error, respectively. Error that occurs in the first phase is called sampling variance, which results from selecting any sample from a sampling universe. Sampling variance can be minimized by selecting an adequately large number of samples from all units that are available in a given stratum. In the second phase (in units selected for bounded counts), there is error associated with the measurement of any particular unit abundance (measurement error or precision) due to variation of dive counts within units surveyed multiple times.

For each unit selected for a bounded count (multiple passes), individual pass counts were ordered from highest to lowest, and unit abundance was estimated as

$$\tilde{y}_{Bk} = d_m + (d_m - d_{m-1})$$

where $\tilde{y}_{Bk}$ = the bounded count estimate of "true" abundance in unit k, d_m is the largest of the four counts for the unit, and d_{m-1} is the second largest of the four counts.

For example, if a unit was snorkeled four times with pass counts of 6, 7, 9, and 6 fish, the ordered counts would be 9, 7, 6, and 6. The difference between the highest count (9) and the next highest count (7) is 2, and would be added to the highest pass count of 9, for an abundance estimate of 11 fish in the unit.

The estimate of error, or mean square error (MSE), around the unit abundance estimate was calculated as

$$\widehat{MSE}_{\tilde{y}_{Bk}} = (d_m - d_{m-1})^2$$

In the preceding example, the MSE would equal the squared difference between the highest count (9) and the next highest count (7), which would equal 4. The 95% confidence intervals would be twice the square root of MSE, again, which would equal 4, for a final unit abundance estimate of 11 ± 4 (7 – 15).

For each stratum in which surveys were conducted, the total stratum abundance ($\hat{Y}_D$) is estimated as

$$\hat{Y}_D = \mathrm{N}\bar{\tilde{y}}_{BD}\frac{\bar{x}_1}{\bar{x}_2}$$

where N is the total number of habitat units within stratum *D*, and $\bar{\tilde{y}}_{BD}$ is the mean estimated total abundance for all units in stratum *D* for which bounded counts were performed. The last term in the equation is the mean of the first pass counts in habitat units that were dove only once ($\bar{x}_1$) divided by the mean of the first pass counts in habitat units that were dove four times ($\bar{x}_2$). This is an adjustment factor that accounts for the observation probability during the snorkel surveys (i.e., the difference between a unit abundance derived from a single-pass survey versus a four-pass survey).

Estimates of error around the total stratum abundance were calculated as

$$\hat{V}(\hat{Y}_D) = N^2(1-f_1)\frac{s_{\tilde{y}}^2}{n_1} + N^2(1-f_2)\left(\frac{\bar{x}_1}{\bar{x}_2}\right)^2\frac{s_{\tilde{y}|x}^2}{n_2}$$

where f_1 and f_2 are the sampling fractions for the first and second phases, respectively; n_1 and n_2 are the numbers of units that are sampled in the first and second phases, respectively. The variation in the unit counts in the first phase, $s_{\tilde{y}}^2$, was calculated as

$$s_{\tilde{y}}^2 = \frac{1}{n_2-1}\sum_{k=1}^{n_2}(\tilde{y}_{Bk} - \bar{\tilde{y}}_{BD})^2$$

where $\tilde{y}_{Bk}$ is the estimated abundance in the k^{th} second phase sample and $\bar{\tilde{y}}_{BD}$ is the mean abundance over all second phase samples in stratum *D*. The conditional variation (i.e., variation that arises from selecting particular second phase samples), $s_{\tilde{y}|x}^2$, was calculated as

$$s_{\tilde{y}|x}^2 = \frac{1}{n_2-1}\sum_{k=1}^{n_2}\left[MSE_{\tilde{y}_{Bk}} + (\tilde{y}_{Bk} - \bar{\tilde{y}}_{BD}\frac{x_{Bk}}{\bar{x}_2})^2\right]$$

where x_{Bk} is the first pass dive count in unit k.

Sampling under a stratified design such as the one employed in this study is considered independent across the different habitat strata (run, riffle, pool; *D* = 1, 2, 3), so that estimates of total abundance for each of the habitat types, $\hat{Y}_D$, and their corresponding sampling variances, $\hat{V}(\hat{Y}_D)$, can be combined across strata (Thompson 2002):

$$\hat{Y} = \sum_{D=1}^{3} \hat{Y}_D$$

and

$$\hat{V}(\hat{Y}) = \sum_{D=1}^{3} \hat{V}(\hat{Y}_D)$$

Notably, though bias of this method is considered negligible at low abundances (less than approximately 30 individuals per unit), special scenarios can lead to a failure of this estimator. More specifically, at very low abundances of the target species, failure to observe the species (or size category) during the first pass of (all) bounded counts in a given stratum results in a zero in the denominator of the count ratio between single- and bounded count units (i.e., $\bar{x}_2$, see formula for estimation of total stratum abundance). In the vast majority of surveys, random or systematic sampling of a large number of units ensures that this ratio is close to 1 (e.g., in the 2013 survey, this ratio was between 0.95 and 1.05), resulting in a slight adjustment to the estimated stratum abundance (i.e., the "bias correction").

However, the chance of estimator failure (or unrealistic estimates) increases with the number of size classes and habitat categories for which abundance is to be estimated. In other words, the chance of observing *at least one* individual of a particular species during one or more first-pass MBC counts for a given habitat category is relatively high (given that a sufficiently large number of units are selected for bounded counts). In contrast, the chance of observing individuals belonging to *each* of several size classes is lower, which increases the chance of estimator failure for a given size class and habitat category.

Such was the case for two habitat type and size class categories in 2014, as abundance estimates could not be calculated for *O. mykiss* larger than 300 mm in pools and smaller than 150 mm in runs (i.e., the absence of fish observations resulted in a zero in the denominator of certain key calculations). As a consequence, overall abundance for each habitat type was estimated for all size classes combined, and size-class specific estimates of abundance were calculated when possible (i.e., for all size classes and habitats, with the exception of the two mentioned above). For the same reasons (lack of fish observations during first pass snorkel counts), it was not feasible to obtain abundance estimates specific to the reach of Big Chico Creek within the BCCER.

To permit a comparison between 2013 and 2014 survey results of *O. mykiss* abundance within the Reserve, an "index of abundance" (rather than an abundance estimate) was calculated as follows: average counts obtained during the first pass of each surveyed unit in a particular habitat category were extrapolated to the number of units of the respective category located within Reserve boundaries, and the resulting indices were summed over the three habitat categories.

Note that the estimates of abundance do not account for cascade habitat units that were not sampled due to safety concerns and poor visibility. This habitat type accounted for 6.8 percent of the total length of the stream within the study area (Table 1).

Results

Habitat Mapping and Unit Selection

According to our classification, the reach of Big Chico Creek between the downstream border of the Reserve and Higgin's Hole consists of 332 distinct habitat units (72 pools, 86 riffles, 127 runs, and 47 cascades; Table 1). Snorkel surveys were conducted in 14 pools, 26 runs, and 18 riffles. Additionally, 24 of the 58 surveyed units were selected for bounded counts.

Table 1. Habitat composition and percentage surveyed during snorkel surveys conducted on Big Chico Creek in July 2014.

Habitat Type	Count of Type	Sum of Length (m)	Percent by Length	Units Surveyed	Length of Units Surveyed (m)	Percent of Type Surveyed
Pool	72	4,332	40.3	14	633	19.4
Riffle	86	2,125	19.9	18	326	20.9
Run	127	3,546	33.0	26	676	20.5
Cascade	47	735	6.8	0	0	0.0
Total	332	10,738	100	58	1,635	17.5

Fish Abundance

Overall, four species of fish were observed during the Big Chico Creek snorkel survey, including: rainbow trout, brown trout, Sacramento sucker, and California roach. With the exception of California roach, which were impractically numerous to count in nearly every habitat unit that was snorkeled, rainbow trout were the most abundant species observed, followed by Sacramento suckers and brown trout. We observed 130 rainbow trout, 44 Sacramento suckers, and 3 brown trout during the first pass of snorkel surveys (Figure 2). We estimated that there were approximately 3,220 rainbow trout in the reach of Big Chico Creek within the study area, or approximately 482 fish per mile. Note that this estimate of total abundance was calculated using the combined size-classes for each surveyed unit, rather than summing estimates of individual size classes (see Materials and Methods - Fish Abundance). Estimates could not be calculated for the other species due to a minimal number of observations.

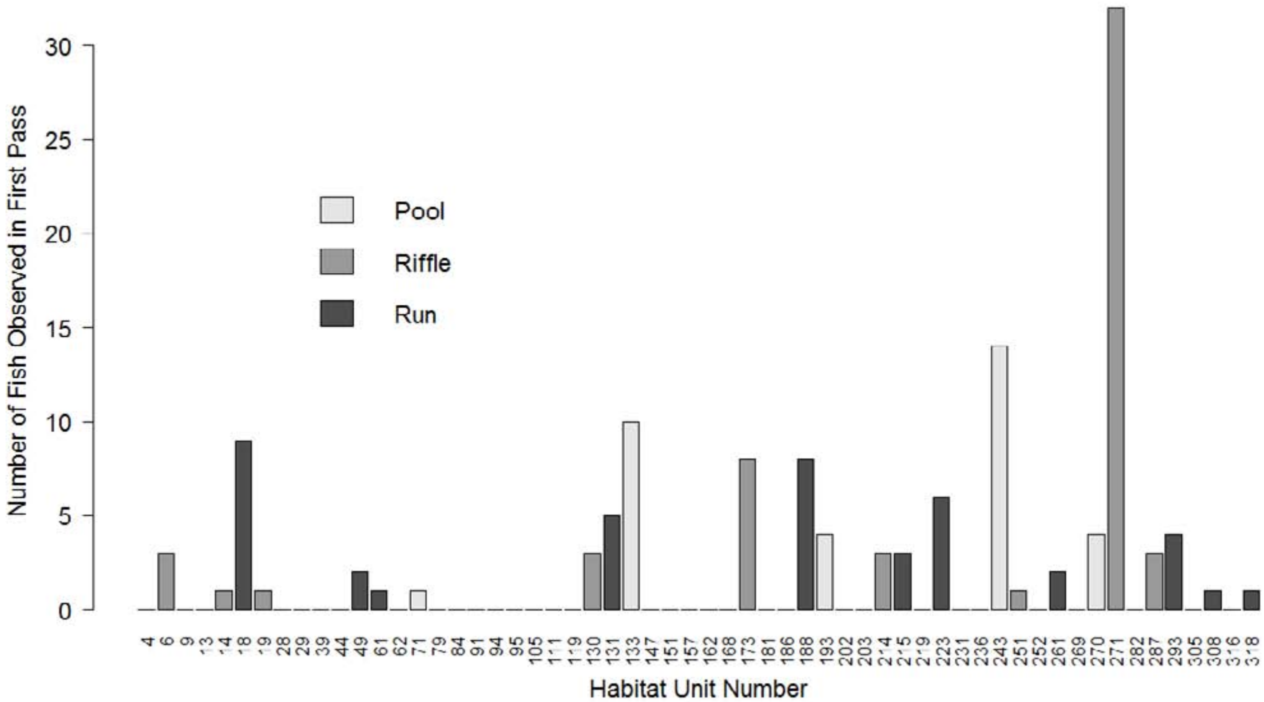

Figure 2. Number of *Oncorhynchus mykiss* (all size classes combined) observed during the first pass of snorkel surveys conducted on July 21-25, 2014, on Big Chico Creek.

Overall, the majority of rainbow trout were observed in riffles and pools (39% and 41%, respectively). We estimated that there were approximately 1,270 trout inhabiting riffles, 1,310 rainbow trout inhabiting pools, and 640 rainbow trout inhabiting runs in the study area (Figure 3). While rainbow trout were observed in half of the runs in the study area (Table 2), the comparatively low overall abundance of the species in this habitat type is attributable to the low density of fish in this stratum.

Table 2. Percentage of habitat units in which each species (all size classes combined) was observed during snorkel surveys conducted on Big Chico Creek during July 21-25, 2014.

Common Name	Scientific Name	Pool	Riffle	Run
Rainbow trout	*Oncorhynchus mykiss*	40.0	55.5	50.0
Brown trout	*Salmo trutta*	7.1	5.5	3.8
Sacramento sucker	*Catostomus occidentalis*	50.0	5.5	15.4
California roach	*Lavinia symmetricus*	100.0	100.0	100.0

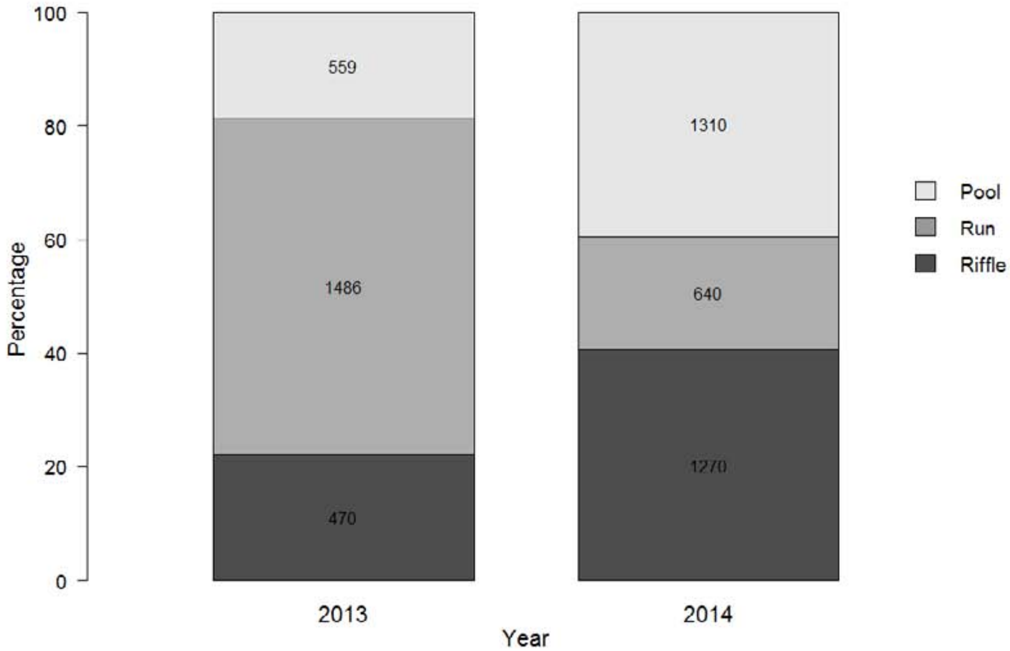

Figure 3. Estimated number of *O. mykiss*, by habitat type, in Big Chico Creek, July 2014.

When the distinct size categories are taken into consideration for abundance estimation, estimates were not possible for all habitat type/size class combinations, and the following abundance estimates *do not* include the strata-specific populations for *O. mykiss* larger than 300 mm in pools, and smaller than 150 mm in runs. Excluding these categories, we estimated that there were 1,067 juvenile rainbow trout (< 150 mm), 1,511 rainbow trout between 150 and 300 mm in length, and 458 rainbow trout larger than 300 mm in the study area (Figure 4). The majority of Sacramento sucker (42 out of 44) and all of the brown trout we observed were juveniles.

Indices of abundance, calculated to compare abundance of *O. mykiss* within the boundaries of the ecological Reserve, were approximately 347 and 88 fish for 2013 and 2014, respectively. This is indicative of as much as a 75% decrease in *O. mykiss* abundance on the BCCER.

In addition to the fish species mentioned in preceding paragraphs, we made 22 unique observations of Western pond turtles (*Actinemys marmorata*) during our survey. They were observed in all surveyed habitat types but were most frequently seen in pools.

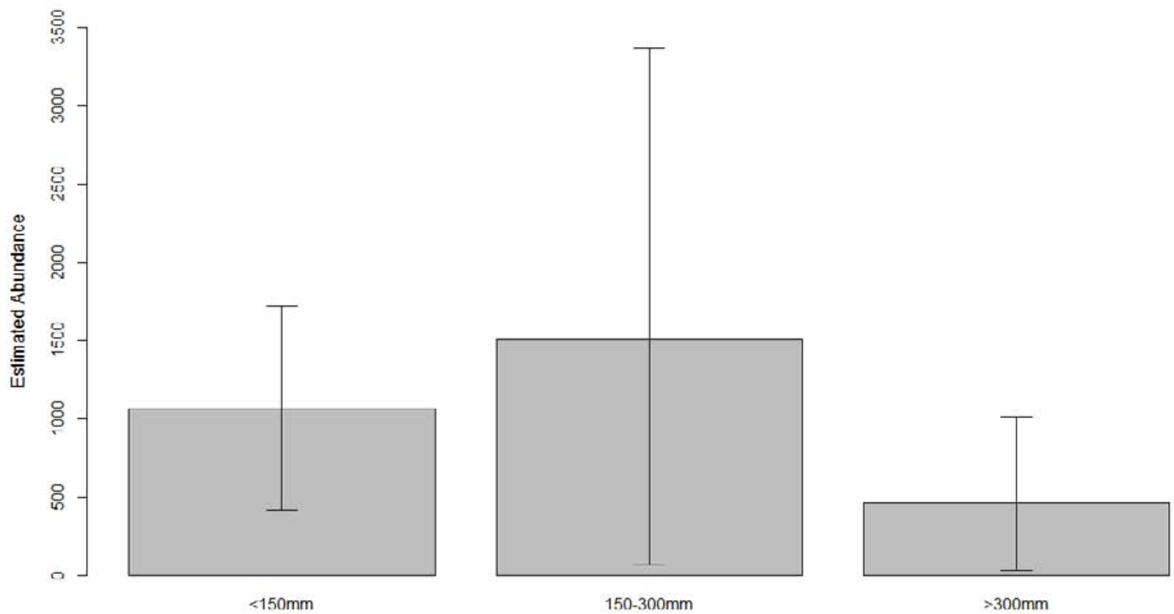

Figure 4. Estimated number of *O. mykiss*, by size category, in Big Chico Creek, July 2014. Error bars represent one standard error.

Stream Characteristics

Stream flow

Discharge data were obtained from the closest CDEC station gauge (BIC), located just upstream of Five-Mile Recreation Area in Upper Bidwell Park (Figure 1). Discharge at this location varied between six and eight cubic feet per second (cfs) during the 2014 survey, which is 22.4 cfs lower than the 10-year average for this period (Figure 5). As these flow measurements were recorded more than four miles downstream of the sampling area, reported discharge may not perfectly correspond to stream flow below Higgin's Hole and on the Big Chico Creek Ecological Reserve.

Water temperature

Temperature data were recorded at the downstream end of each unit prior to snorkeling. Instantaneous temperatures ranged from 17.3 - 23.4 °C (63.1 - 74.1 °F), depending on location and time of day. Additionally, two temperature loggers were deployed near the upper and lower boundaries of the Reserve to monitor water temperatures year round (Figure 1). Mean daily water temperatures during the survey period were 20.4 °C and 21.7 °C at the upper and lower sensor, respectively, and ranged from 0.02 °C to 25.5 °C over the course of the past year (Figure 6).

Substrates and instream cover

Cobble (diameter 6.4 - 25 cm) and boulder (diameter > 25 cm) were the two most common substrates within wetted areas of the mapped stream reach, and the dominant substrate category in 34% and 35% of habitat units, respectively. Bedrock, gravel, and sand characterized some of the units, though these rarely constituted the predominant substrate type. Most units (~44%) had no predominant cover type, and boulders, live vegetation, and bubble curtains were considered the predominant cover in 23%, 8%, and 8% of the units, respectively. Large woody debris (>10 cm diameter and >1 m length) was present in 26% of the surveyed units.

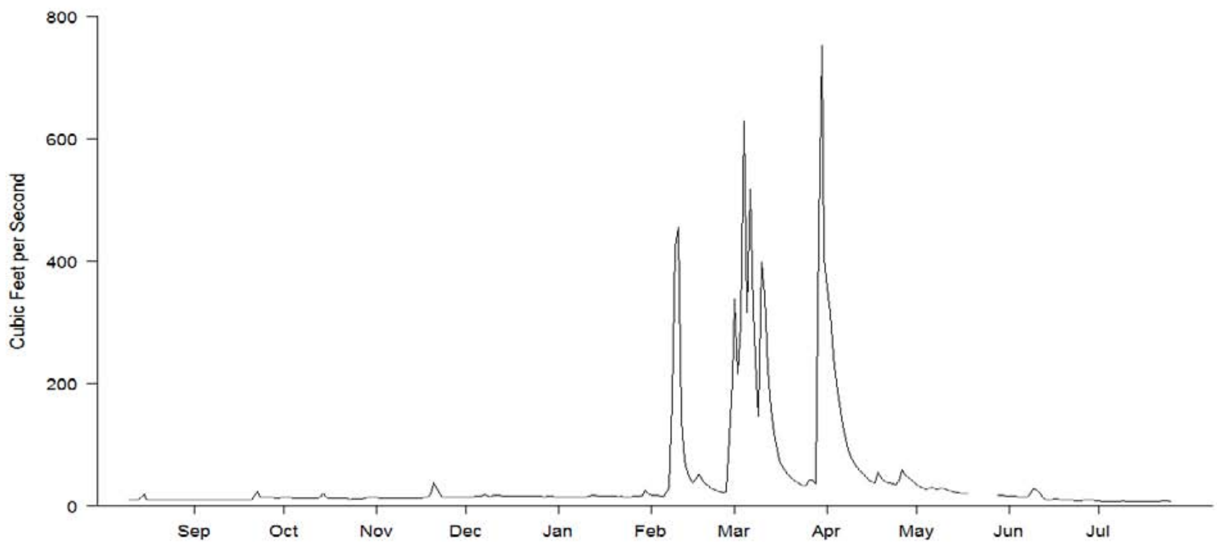

Figure 5. Average daily discharge of Big Chico Creek, as recorded at the Big Chico Creek near Chico station gauge (BIC; California Data Exchange Center), between August 10, 2013, and July 25, 2014.

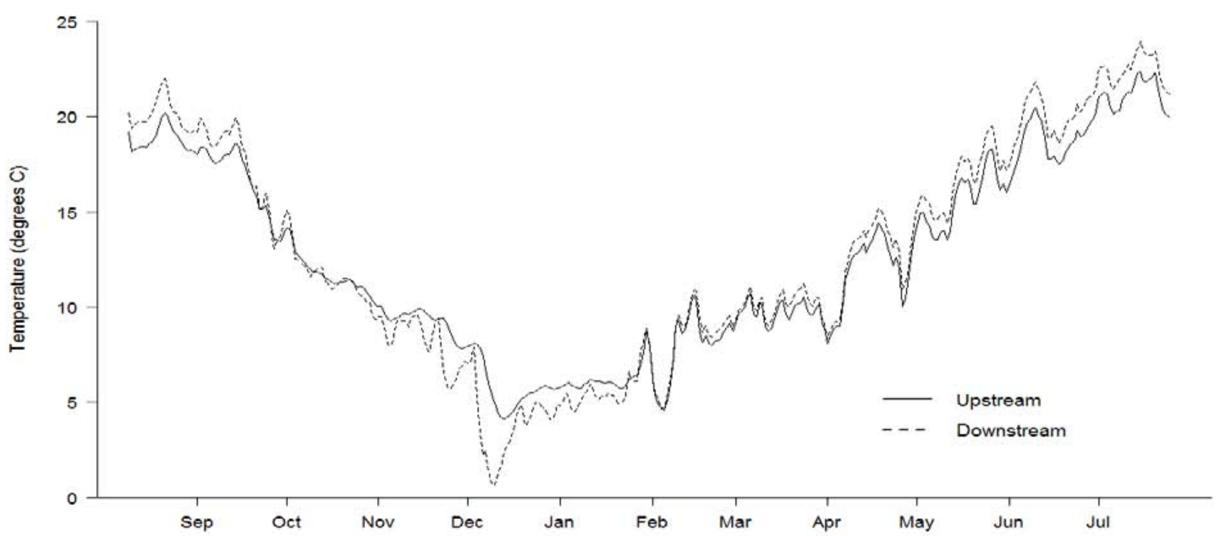

Figure 6. Average daily temperature of Big Chico Creek, as recorded near the upstream and downstream boundaries of the Big Chico Creek Ecological Reserve, between August 10, 2013, and July 25, 2014.

Discussion

Despite a growing body of scientific literature documenting the ability of resident rainbow trout to produce migratory offspring (e.g., Zimmerman et al. 2009, Christie et al. 2011, Courter et al. 2013), the amount of information regarding the abundance of rainbow trout in anadromous waters of Northern California is very limited. To our knowledge, this study, along with a concurrent survey on Deer Creek, are the only recent studies that attempt to quantify summertime abundance of rainbow trout in eastside tributaries of the Sacramento River. While we do not know how many, if any, of the rainbow trout inhabiting Big Chico Creek within the study area may emigrate and assume the migratory life history that typifies steelhead, the abundance estimates presented in this study provide a much-needed and current quantification of "potential steelhead" in the Northern Central Valley. As this survey encompassed the entirety of suitable over-summering habitat for *O. mykiss* in the anadromous portion of Big Chico Creek, we consider the abundance estimates reported herein to be an important reference for comparison to other local tributaries of the Sacramento River.

While a similar survey in 2013 was limited to the 4.5 miles of Big Chico Creek located within the boundaries of the BCCER (FISHBIO 2014), we expanded our efforts in 2014 to include the additional 2.5 miles between the BCCER and Higgin's Hole, the barrier to anadromy. This reach upstream of the Reserve appeared to be more productive than the reach within the BCCER, indicated by the large proportion (approximately 57%) of all rainbow trout observed in this section (based on first pass dive counts only) despite its comparatively short length.

Several lines of evidence suggest that both densities and overall abundances of trout were lower in 2014 than they were in 2013. While estimates of total abundance could not be calculated specifically for the reach within the Reserve (due to lack of observed fish in many units), indices of abundance suggest that the rainbow trout population within the Reserve may have decreased by as much as 75% compared to 2013 (indices of 347 and 88 fish in 2013 and 2014, respectively). The observed stark differences in localized abundance and reduced overall densities (561 vs. 482 individuals/mile in 2013 and 2014, respectively) may be at least partially attributable to ongoing severe current drought conditions in California. Reduced flow and increased water temperatures may have resulted in distributional shifts of the species within the watershed. For example, more than half of all *O. mykiss* in this survey were observed in the uppermost 2.5 miles of creek). The maximum water temperature measured near the upstream boundary of the Reserve during the survey period was 22.4 °C. Avoidance for juvenile *O. mykiss* has been measured at temperatures as low as 20 °C (Kaya et al. 1977). Additionally, increases in physiological stress and decreases in forage activity have been observed at temperatures as low as 22 °C (Nielsen et al. 2014). Therefore, it seems reasonable to assume that distributional shifts may have occurred during periods of elevated water temperatures in Big Chico Creek.

Differences in estimated abundance by habitat type indicate a distributional shift in habitat use between 2013 and 2014. In 2013, the majority of fish occupied runs (approximately 60%), followed by riffles and pools. Conversely, in 2014, the abundance estimated for runs (20% of the population) was approximately half of pool and riffle abundance (approximately 40% each). In

2014, a higher proportion of the population may have been concentrated in cascades where visual sampling is not feasible, but where oxygen content is highest and bubbles provide cover in an otherwise mostly clear and shallow stream. The high proportion of individuals observed in riffles appears to corroborate a distributional shift towards areas with turbulent water. An additional reason for lower observed abundance in 2014 may be the higher propensity of juvenile *O. mykiss* to assume a migratory/anadromous life history when water temperatures are elevated (Sloat and Reeves 2014; Figure 6). Consequently, the low number of juveniles estimated in 2014 may reflect a higher-than-normal proportion of juvenile individuals that emigrated from Big Chico Creek. Despite several potential reasons for perceived abundance differences between 2013 and 2014, these explanations are purely speculative.

Compared to historical accounts of the fish community of Big Chico Creek, several species were conspicuously absent from the surveyed reach in 2014. Spring-run Chinook salmon, Pacific lamprey, riffle sculpin, Sacramento pikeminnow, hardhead, or large Sacramento sucker were not observed. Historically, these species comprised a large percentage of the fish community in the foothill zone of Big Chico Creek. Our findings, in corroboration with our observations from 2013 and historical observations made by Dr. Maslin, are suggestive of long-term detrimental effects of the rotenone treatment on native, non-salmonid fish species. However, the absence of anadromous fishes such as spring-run Chinook salmon is likely due to factors other than the piscicide treatment. In recent years, salmon escapement has been intermittent, ranging from zero to 299 since 2001 (six years with no escapement, average of all other years = 75; CDFW 2013a), and is probably most affected by the timing of high flows through Iron Canyon. In 2014, two adult Chinook salmon were reported to be present on the Reserve in a unit that was not selected for sampling in our survey. Additionally, ten spring-run Chinook were observed holding in Salmon Hole, a large pool just downstream of Iron Canyon, in late spring. Neither the salmon observed on the BCCER nor those seen in Salmon Hole persisted through the summer.

It should be noted that a lack of observations during snorkel surveys does not constitute absence of a particular species. As only 17.5% of the total creek length within the study area was surveyed, it is possible that some of the species that we did not observe are present in Big Chico Creek in habitat units not included in our sample. Additionally, as snorkel surveys are designed to detect a particular suite of species, observations of non-target species can often be affected by species-specific behaviors (e.g., burrowing by lamprey ammocoetes). Other factors that affect fish detectability (visibility, temperature, time of day, and fish size) are likely negligible considering the relatively small size and low turbidity of this stream during the summer months.

Despite the above-described limitations, it appears that the relative species composition of Big Chico Creek was different during the 2014 survey compared to the previous year. The population of rainbow trout in the BCCER was reduced by as much as 75%, although trout density increased between the upstream boundary of the Reserve and Higgin's Hole. Only two exotic brown trout were observed on the Reserve in 2014 compared to 16 the previous year. Observations of Sacramento sucker on the Reserve were similar to the numbers seen in 2013 (38 first-pass dive observations in 2014; 36 in 2013). Though not quantified, the relative abundant population of native California roach appeared to be consistent in both years of surveying. Future surveys may also document the presence of spring-run Chinook salmon, Pacific lamprey, riffle sculpin, Sacramento pikeminnow, hardhead, and large Sacramento suckers, all of which were not observed in this study. Furthermore, an expansion of the study area to other comparable, nearby tributaries of the Sacramento River (e.g., Deer Creek, Butte Creek, and others) would help create a more complete assessment of the trout population in the northern Central Valley. Such an expansion would provide for comparative abundance estimates and better quantify the status and recovery potential inherent to resident rainbow trout populations.

The abundance estimates reported in this study demonstrate that substantial populations of *O. mykiss* exist even in relatively small tributaries to the Sacramento River. This highlights the importance of such streams as "gene banks" and potential source populations of the steelhead life-history type in California's Central Valley. Furthermore, the continued presence of resident populations should warrant the consideration of these population segments and such small streams in future status assessments of *O. mykiss*. In the meantime, population estimates presented herein can serve to help evaluate trends and inter-annual comparisons of fish community composition and abundance.

Lastly, the relatively high density of *O. mykiss* estimated in this study is a testament to the importance of Big Chico Creek, and specifically the Big Chico Creek Ecological Reserve, to the conservation and recovery of Central Valley steelhead. The number of trout observed in this survey, although less than the previous year, confirms the importance of this habitat to the threatened species, and the need for continual monitoring and conservation of resident trout populations.

Acknowledgements

We are grateful to everyone at the Big Chico Creek Ecological Reserve, as well as landowners upstream of the Reserve, for providing assistance in conducting the survey and making this project logistically feasible by allowing us to access private property. In particular, we would like to thank Packard Greer, Jeff Mott, Dulcy Schroeder, Jim Crane, Roger Mathews, Ken Grossman and Katie Grossman. We would also like to thank Dr. Paul Maslin for his initial research and his continued interest in native fish communities. Thanks to Christian Chin, who interned on the project. In addition to the report authors, other contributing FISHBIO staff included Stephen Zipper, Dee Thao, Courtney Kopp, and Gabriel Kopp. Funding for this project was provided by FISHBIO.

Bibliography

Allen, M. and T. Gast. 2007. Use of dive counts to estimate fish population abundance in the Rock Creek-Cresta reaches of the North Fork Feather River, California: 2006 Final Report. Prepared for Pacific Gas & Electric Company by Thomas R. Payne & Associates, Arcata, CA. May 31, 2007.

Big Chico Creek Watershed Alliance. 1997. Big Chico Creek Watershed Project, Existing Conditions Report. Chico, CA. <*http://www.bigchicocreek.org/nodes/library/ecr/*>.

Bradford, M. J. and P. S. Higgins. 2001. Habitat-, season-, and size-specific variation in diel activity patterns of juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*). Canadian Journal of Fisheries and Aquatic Sciences 58: 365-374.

CDFW [California Department of Fish and Wildlife]. 2013a. Fisheries Branch Anadromous Assessment – GrandTab. Compiled on 4/18/2013. Accessed on 1/30/2014.

CDFW. 2013b. Northern Region Files. Heritage and Wild Trout Field Report - Antelope Creek, Tehama Co. Unpublished Report.

Christie M. R., M. L. Marine and M. S. Blouin. 2011. Who are the missing parents? Grandparentage analysis identifies multiple sources of gene flow into a wild population. Molecular Ecology 20: 1263–1276.

Courter, I. I., D. B. Child, J. A. Hobbs, T. M. Garrison, J. J.G. Glessner and S. Duery. 2013. Resident rainbow trout produce anadromous offspring in a large interior watershed. Canadian Journal of Fisheries and Aquatic Sciences 70: 701-710.

DWR [Department of Water Resources]. 2002. Iron Canyon and Bear Hole Fish Passage Project on Big Chico Creek - Preliminary Engineering Technical Report. Sacramento, CA. <*http://www.fws.gov/stockton/afrp/documents/BCC_Preliminary_Report_Final.pdf*>.

Eilers, C. D., J. Bergman, and R. Nielson. 2010. A comprehensive monitoring plan for steelhead (*Oncorhynchus mykiss*) in the California Central Valley. Fisheries Branch Administrative Report Number: 2010-2. Department of Fish and Game, Sacramento, CA. October 2010.

Fleming, I. A. and J. D. Reynolds. 2004. Salmonid breeding systems. *In* Evolution illuminated: salmon and their relatives. *Edited by* A.P. Hendry and S.C. Stearns. Oxford University Press, New York. pp. 264 - 294.

Hagen, J. and J. Baxter. 2005. Accuracy of diver counts of fluvial rainbow trout relative to horizontal underwater visibility. North American Journal of Fisheries Management 25: 1367-1377.

Hagen, J., S. Decker, J. Korman, and R. G. Bison. 2010. Effectiveness of night snorkeling for estimating steelhead parr abundance in a large river basin. North American Journal of Fisheries Management 30: 1303-1314.

Heath D. D., C. M. Bettles, S. Jamieson, I. Stasiak and M. F. Docker. 2008. Genetic differentiation among sympatric migratory and resident life history forms of rainbow trout in British Columbia. Transaction of the American Fisheries Society 137: 1268–1277.

Kaya, C. M., L. R. Kaeding, and D. E. Burkhalter. 1977. Use of cold-water by rainbow and brown trout in a geothemally heated stream. The Progressive Fish-Culturist 39:37-38.

Lindley, S. T., R. S. Schick, A. Agrawal, M. Goslin, T. E. Pearson, E. Mora, J. J. Anderson, B. May, S. Greene, C. Hanson, A. Low, D. McEwan, R. B. MacFarlane, C. Swanson, and J. G. Williams. 2006. Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary and Watershed Science 4 (1).

Lindley, S. T., R. S. Schick, E. Mora, P. B. Adams, J. J. Anderson, S. Greene, C. Hanson, B. P. May, D. R. McEwan, R. B. MacFarlane, C. Swanson, and J. G. Williams. 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science 5(1).

Maslin, P. E. 1997a. Long term effect of Rotenone treatment on the fish community of Big Chico Creek, California. < *http://www.sgreen.us/pmaslin/rsrch/rotenone/Intro.html* >.

Maslin, P. E. 1997b. Big Chico Creek at Highway 32, Tehama County, California. < *http://www.sgreen.us/pmaslin/rsrch/hwy32/Chico.Creek32.html* >.

McEwan, D. R. 2001. Central Valley steelhead. Pages 1–43 *In* R. L. Brown, editor. Contributions to the biology of Central Valley salmonids. Vol. 1. California Department of Fish and Game, Sacramento, CA.

Mohr, M. S. and D. G. Hankin. 2005. Two-phase survey designs for estimation of fish abundance in small streams. Unpublished Manuscript. Preprint from D.G. Hankin, Department of Fisheries Biology, Humboldt State University, Arcata, CA.

Moyle, P. B. and R. D. Nichols. 1974. Decline of the native fish fauna of the Sierra Nevada foothills, Central Califnorna. The American Midland Naturalist 92: 72-83.

Moyle, P. B. and J. E. Williams. 1990. Biodiversity loss in the temperate zone: decline of the native fish fauna of California. Conservation Biology 4: 275-284.

Mullner, S., W. Hubert, and T. Wesche. 1998. Snorkeling as an alternative to depletion electrofishing for estimating abundance and length-class frequencies of trout in small streams. North American Journal of Fisheries Management 18: 947-953.

National Marine Fisheries Service. 2009. Public draft recovery plan for the Evolutionarily Significant Units of Sacramento River winter-run Chinook salmon and Central Valley spring-run Chinook salmon and the Distinct Population Segment of Central Valley steelhead. Sacramento Protected Resources Division, Sacramento, CA. October 2009.

Nielsen, J. L., T. E. Lisle, and V. Ozaki. 1994. Thermally stratified pools and their use by steelhead in northern California streams. Transactions of the American Fisheries Society 123:613-626.

Null, R. E., K. S. Niemela and S. F. Hamelberg, 2012. Post-spawn migrations of hatchery-origin *Oncorhynchus mykiss* kelts in the Central Valley of California. Environmental Biology of Fishes 96: 341-353.

O'Neal, J. S. 2007. Snorkel Surveys. Pages 325-340 *In* D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons, editors. Salmonid Field Protocols Handbook. Techniques for Assessing Status and Trends in Salmon and Trout Populations. American Fisheries Society, Bethesda, MD.

Satterthwaite, W. H., M. P. Beakes, E. M. Collins, D. R. Swank, J. E. Merz, R. G. Titus, S. M. Sogard, and M. Mangel. 2010. State-dependent life history models in a changing (and regulated) environment: steelhead in the California Central Valley. Evolutionary Applications 3: 221-243.

Schill, D. J., G. W. LaBar, E. R. J. M. Mamer, and K. A. Meyer. 2010. Sex-ratio, fecundity, and models predicting length at sexual maturity of redband trout in Idaho desert streams. North American Journal of Fisheries Management 30: 1352 - 1363.

Sloat, M. R. and G. H. Reeves. 2014. Individual condition, standard metabolic rate, and rearing temperature influence steelhead and rainbow (Oncorhynchus mykiss) life histories. Canadian Journal of Fisheries and Aquatic Sciences 71: 491-501.

Teo S. L. H., P. T. Sandstom, E. D. Chapman, R. E. Null, K. Brown, A. P. Klimley and B. A. Block. 2011. Archival and acoustic tags reveal the post-spawning migrations, diving behavior, and thermal habitat of hatchery-origin Sacramento River steelhead kelts (*Oncorhynchus mykiss*). Environmental Biology of Fishes 96: 175-187.

Thompson, S. K. 2002. Sampling, 2nd Edition. John Wiley & Sons, Inc., New York, New York.

U.S. Fish & Wildlife Service. Anadromous Fish Restoration Program. *<http://www.fws.gov/stockton/afrp/>.*

Williams, J. G., J. J. Anderson, S. Greene, C. Hanson, S. T. Lindley, A. Low, B. P. May, D. McEwan, M. S. Mohr, B. MacFarlane, and C. Swanson. 2007. Monitoring and research needed to manage the recovery of threatened and endangered Chinook and steelhead in the Sacramento-San Joaquin basin. NOAA Technical Memorandum NMFS-SWFSC-399.

Zimmerman, C. E., and G. H. Reeves. 2000. Population structure of sympatric anadromous and nonanadromous *Oncorhynchus mykiss* : evidence from spawning surveys and otolith microchemistry. Canadian Journal of Fisheries and Aquatic Sciences 57:2152–2162.

Zimmerman, C., G. Edwards, and K. Perry. 2009. Maternal origin and migratory history of steelhead and rainbow trout captured in rivers of the Central Valley, California. Transactions of the American Fisheries Society 138: 280-291.