Southern California steelhead life cycle monitoring in the Ventura River watershed

2019-2020

California Department of Fish and Wildlife

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ABSTRACT

This study is a continuation of long term monitoring initiated by the California Department of Fish and Wildlife and the Pacific States Marine Fisheries Commission in 2013 to ascertain the abundance and spatial structure of southern California steelhead (*Oncorhynchus mykiss*) via operation of a life cycle monitoring station. DIDSON and ARIS sonar cameras provided unbiased counts of anadromous adult *O. mykiss*, PIT Tag arrays provide smoltification rates and marine survival, and spatial structure and resident abundance were ascertained through comprehensive spawning ground surveys in the Ventura River, a watershed assigned a high priority for steelhead recovery action (Core 1).

Sonar cameras are a reliable method of obtaining adult counts in southern California systems because they can collect data at night and under dynamic stream conditions. Sonar footage was analyzed for observations of targets $\geq$ 40 cm. Every observation was measured for length and classified to species. In 2020, 178 days of footage were acquired with a consistently high detection efficiency. A total of 318 observations were recorded at the Ventura River site with 0 *O. mykiss* and 289 Common Carp (*Cyprinus carpio)* detections. Overall, this project demonstrated the efficient use of sonar cameras for steelhead abundance monitoring in southern California streams despite the lack of observations.

Two PIT Tag arrays were deployed along Ventura River and San Antonio Creek on December 3, 2019 and January 2 2020, respectively. Antennas were removed June 2, 2020 and marker tags recording on 15-minute intervals indicated operational efficiency of 77% and 99% at each site, respectively, during this period. No up- nor downstream migrants were recorded at either site, although no *O. mykiss* have been PIT tagged in anadromous waters in the Ventura River watershed. Antennas remained operational and secure during major storm events indicating anchoring techniques were adequate in flashy southern stream systems. High operational efficiency and successful operation of the antennas will help further PIT tag array development methodologies that are applicable to southern California.

Due to sampling concerns related to the low abundance of *O. mykiss* in southern California watersheds and the potential for patchy distribution, spawning surveys were conducted as a complete census of available habitat. During the 2019-2020 winter seasons, surveys were conducted from December through May on a bi-weekly basis on 19 survey reaches covering 46.9 stream miles when environmental conditions allowed. Three *O. mykiss redds* and 44 bankside observations, all in Murietta Creek, were observed above a total barrier to anadromy during the 2019-2020 winter season. No redds were observed in anadromous waters. Mean redd area was similar to that observed in previous years whereas redd life was longer, which may be attributed to the timing of high flow events.

INTRODUCTION

Southern California steelhead trout (*Oncorhynchus mykiss*) populations have declined dramatically throughout their historic range. Consequently, steelhead trout inhabiting the area from the Santa Maria River to the U.S.-Mexico border were listed as a federally endangered distinct population segment (DPS) (ESA; NMFS 2012). The ESA mandated recovery plan outlines goals to ensure the persistence of viable populations of anadromous *O. mykiss* across the DPS (NMFS 2012). In Fish Bulletin 180 (Adams et al. 2011), The California Department of Fish and Wildlife developed a framework to implement monitoring to track recovery progress. This framework is based on assessment of four viability metrics (i.e., Viable Salmonid Population parameters) composed of abundance, productivity, spatial structure, and diversity (McElhany 2000, NMFS 2016).

Unbiased estimates of anadromous adults are required to assess abundance for populations encompassed by the DPS (NMFS 2016). As part of the California Coastal Salmonid Monitoring Plan, (CMP), Fish Bulletin 180 suggests the use of sonar cameras (i.e., DIDSON) to collect counts of anadromous adults in focal streams including Topanga Creek. Developed by Sound Metrics, DIDSON produces near video-quality imagery and allows for data collection at night and during periods of high flow and turbidity (Sound Metrics 2018). These conditions are commonplace in southern California where highly episodic flows result in dynamic hydrology. Additionally, DIDSON cameras allow for the passive collection of data and avoids alterations to steelhead behavior or inadvertent harm to a listed species (Pipal 2012).

To provide an index of effective population size (abundance) and an estimation of spatial structure, redd surveys were conducted as a complete census of available spawning habitat in the Ventura River watershed. Previous studies using redd surveys have demonstrated that steelhead and resident trout redds can be distinguished by redd size (Zimmerman and Reeves 2000). This information provides insight into the complex interplay between resident and anadromous life history strategies in focal watersheds. Furthermore, pairing redd counts with abundance data provided by DIDSON allows calibration of a redd to spawner ratio to be used in nearby stream systems without counting stations, fulfilling a critical component of life cycle monitoring stations (LCM). Finally, redd surveys can provide data on the timing and habitat for spawning activity that may guide management and restoration decisions.

Estimates of smoltification rate and number of outmigrating smolts were produced following the deployment of a passive integrated transponder (PIT) tag array. The Southern Steelhead Recovery Plan (NMFS 2012) identifies the use PIT tags and in-stream reader stations as a viable means to estimate steelhead runs as well as an index of smoltification rate (Boughton 2010). PIT tagging efforts can augment the estimates of diversity and abundance by providing insight about the anadromous fraction of the population. Further, data collected from PIT tag arrays can support estimates of adult counts and out-migrating smolts provided from DIDSON cameras. Placement of PIT Tag antennas in proximity to the DIDSON camera can provide additional confirmation of species identification on recorded tags.

The Ventura River watershed has been a major focus of monitoring and recovery following the federal listing of southern steelhead trout. NMFS began monitoring in 2009 using spawner surveys throughout the watershed to assess steelhead abundance. In 2011, California Department of Fish and Wildlife (CDFW) assumed operations of spawner surveys and deployed a DIDSON camera as a part of the LCM station. Since 2014, Pacific States Marine Fisheries Commission (PSMFC) has collaborated with CDFW in conducting juvenile snorkel surveys and deploying PIT Tag arrays to further augment the LCM in the Ventura River watershed and contribute to the CMP.

This report summarizes the methodologies and results of DIDSON and PIT tag array deployment, redd surveys, data collection, and data analysis within anadromous waters in the Ventura River watershed. The Ventura River is designated in the southern California steelhead recovery plan as being the first focus for recovery action (Core 1, NMFS 2012). Results will aid in the development southern California specific monitoring protocols and will inform resource managers on the status of steelhead populations in these high priority systems.

Study Site – Ventura River

The Ventura River watershed consists of mountainous high peak elevations that transition into a lower elevation coastal terrace before reaching the Pacific Ocean (NMFS 2012). It drains roughly 227 mi^2 and contains approximately 35 mi of anadromous water (NMFS 2012). Both the Casitas and Matilija dams act as total barriers to steelhead passage and prevent migration to spawning and rearing habitat in the upper watershed (NMFS 2012, Figure 1). The Robles Diversion, located on the Ventura main stem 1.5 miles downstream of the confluence of Matilija and North Fork Matilija Creeks, diverts flow from the Ventura River to Lake Casitas and contains a fish-passage facility constructed in 2005 (NMFS 2012). The river flows through the cities of Ojai, Casitas Springs, and Ventura in Ventura County, California. The DIDSON deployment site is located five stream miles upstream of the Pacific Ocean (Figure 1).

Stream flows are highly dependent on rainfall and extensive sections of the main stem exhibit low flow conditions through late spring and summer. A seasonal sandbar between the ocean and the estuary typically prevents access to the watershed until the first large storm event of the season. Without consistent precipitation, flows drop quickly and access to the perennial upper watershed may be limited to brief periods.

In 2018 the Thomas Fire burned 281,893 acres (InciWeb 2018) which included substantial portions of the Ventura River watershed (Klose 2018). A high intensity rain event following the fire lead to widespread flooding and debris flows resulting in road closures. Streams have begun to recover and large sediment loads have been redistributed, but many of the stream channels still bear signs of the debris flows.

Areas of the Ventura River accessible to anadromous adult O. mykiss are inhabited by native and invasive fish species. Native fish species consist of threespine stickleback (*Gasterosteus aculeatus*), prickly sculpin (*Cottus asper*), pacific lamprey (*Lampetra tridentate*) arroyo chub (Gila *orcutti*) and tidewater goby (*Eucyclogobius newberryi*, Walter 2015). Invasive fish species present consist of common carp (*Cyprinus carpio*), black bullhead (*Ameiurus melas*), channel catfish (*Ictalurus punctatus*), green sunfish (*Lepomis cyanellus*), fathead minnow (*Pimephales promelas*), and largemouth bass (*Micropterus salmoides*).

METHODS - DIDSON

Data Collection

The Ventura River DIDSON site, located on property owned and operated by the Ojai Valley Sanitation District, is located where channel profile and substrate composition allow unobstructed views of the full stream channel. A mobile storage container, from which cameras are operated, is situated within a perimeter fence and behind two locked, electronic gates. Sonar cameras were deployed once unobstructed surface flow was established between the site and the ocean and remained deployed as long as conditions allowed for fish migration from the ocean to the monitoring site including periods of heavy rainfall and high flow. Additionally, cameras remained deployed following river mouth closures to allow time for any fish that had entered the system time to migrate to monitoring sites.

A standard DIDSON 300 m unit (Sound Metrics, Lake Forest Park, Washington) and an ARIS Explorer 3000 (Sound Metrics, Lake Forest Park, Washington), both operating in high frequency mode (1.8 MHz and 3.0 MHz respectively), were deployed in the Ventura River on December 5, 2019. Cameras were deployed in parallel to compare functionality under southern California stream conditions (Figure 2). The DIDSON was housed in a Sound Metrics manufactured silt box encased in a custom aluminum box to prevent lens fouling and to prevent damage by floating debris. This was then attached to a X2 pan and tilt rotator (Sound Metrics, Lake Forest Park, Washington) to allow topside aiming and control. The ARIS was housed in a custom stainless-steel box to protect against damage by floating debris. This assembly was attached to an AR2 dual-axis pan/tilt rotator to aim the camera remotely. Each camera and rotator were affixed to a steel, sled foot A- frame mount as described in Larson 2013. Both A-frames were held in place by gravel bags placed on their sled feet, tethers running from the A-frames to adjacent t-posts, and by Duckbill Earth Anchors set into the substrate. To safeguard against theft and potential loss of equipment during peak flows, cameras were tethered to large nearby trees and to an earth anchor installed outside the stream channel. As an added layer of security, motion detecting trail cameras were installed. Deflection panels, consisting of aquaculture mesh fastened to PVC frames, were anchored upstream and downstream of the cameras on both banks. These panels both prevented fish from passing behind cameras and guided them into the field of view of the cameras.

The DIDSON camera was connected to a topside control box via a 60 m DIDSON cable while the ARIS was connected to a command module via a 150 m ARIS cable. Both were connected to Dell Toughbook laptops running DIDSON and ARIS software to interface with the camera and adjust record settings. Focus and frame rate were set automatically by the software based on camera settings. Gain was left at the default maximum value. DIDSON camera window length was set to either 10 m or 5 m depending on stream channel width. ARIS window length was kept at 5 m for all deployments to keep the camera operating in high frequency mode. Footage was captured in 20-minute files and written to external hard drives. Topside electronics and components were powered through uninterruptable power sources connected to permanent onsite power supplied by the Ojai Sanitation District. Site visits were conducted daily to ensure proper camera operation. Prior to removing the cameras, walking surveys were conducted to verify that steelhead migration from the ocean to the camera location was no longer feasible.

Flow data for the Ventura River site were obtained from a U.S. Geological Survey (USGS) stream gauge located 0.7 miles upstream of the DIDSON site. The proximity, and lack of any substantial flow inputs between the DIDSON site and flow gage, make this value a reasonable approximation of flow at the deployment site.

Data Analysis

Sonar files were processed using the echogram function with background subtraction enabled in the Sound Metrics software. Echograms produce a visual representation of the entire file by compressing a given frame into a single pixel width along the full image range and background subtraction allows static objects to be filtered out (Sound Metrics 2012). These processes make moving objects easier to detect and expedites footage review.

All wildlife observations greater than 40 cm in length were recorded, which is the minimum size needed to confidently assign species and corresponds with CDFW's listed lower size limit for steelhead (CDFW 2020).

Targets were measured using the box method per Pipal et al. (2010). The box method requires the reviewer to pause the footage, drag a box around the object seen in frame, and record the value for either the diagonal or width depending on the object's orientation relative to the camera (Pipal et al. 2010). For each observation, up to three measurements were taken from separate frames and then averaged as described in Pipal et al. 2010. Reviewers assigned species to fish observation based on behavioral and morphological cues. In instances where this was not feasible, observations were classified as "unidentified fish species". Observations of non-target aquatic species were designated as either "unidentified terrestrial species", "frog", "turtle", "waterfowl", "snake", "unidentified fish species" or "unknown". In instances where a reviewer was unsure of species designation, files were flagged for further review by a more experienced reviewer. For cases where this occurred in the Ventura River, footage from an ARIS camera or a DIDSON with an alternate view was consulted when available before determination of species was finalized. For each observation, length, direction of travel, species, range from the camera to the target, timestamp, footage quality, confidence in species designation, and pertinent metadata (e.g. site location, date of recording, filename, reviewer name, and date viewed) were recorded.

Ten percent of footage analyzed by each staff member was randomly selected and checked for accuracy by an experienced biologist. Data were entered into an Access database where data rules were enforced to limit entry errors. Data proofing was completed using R software (R Core Team. 2016) to flag potential erroneous values, which were either corrected or omitted as appropriate.

Sonar detection efficiency (D_E) was calculated for each sonar deployment event. This was calculated by subtracting the amount of time the camera's range was limited (T_D) from the total deployment time (T_T) and then dividing by total deployment time.

$$D_E = (T_T - T_D) \ / \ T_T$$

For anadromous *O. mykiss* observations, net movement is calculated to estimate escapement. To calculate net movement (N) for focal species, the total number of downstream observations (D) were subtracted from the total number of upstream observations (U) as recommended by Xie et al. (2002) and put into practice by Larson (2013).

$$N = U - D$$

A net positive number would indicate net movement upstream and vice versa. Considerations for potential confounding of counts by downstream movement of post-spawning adults (i.e., kelts) would be addressed on a case-by-case basis.

Two species in the Ventura River, common carp and pacific lamprey have the potential to be misidentified as steelhead due to the overlap in spatial distribution, temporal cycles, and adult lengths. To learn more about these species, and how they may be differentiated from steelhead;

additional analyses were done for common carp observations in the Ventura River. These observations were compared with synchronous flow data to explore the effect of flow on movement patterns. Additionally, Ventura River common carp observations were binned by hour of the day and classified as either "day" (i.e., the hours from 0600 to 1800) or "night" to characterize patterns in diurnal rhythms. The mean observed length and mean daily count of common carp > 40 cm were reviewed. All analyses were completed using R software.

RESULTS - DIDSON

One hundred and seventy-eight days of sonar footage were recorded from December 5, 2019 to June 2, 2020. The camera was operational and recording for the entirety of the deployment excepting two days from December 19 to December 21 and captured all major flow events (Figure 4). Detection efficiency was high (98.9%) in Ventura River with 4,269.9 hours of recorded footage out of the 4,317.6 hours of deployment. Further, mean visual field range was also high (99.4% ± 0.05%).

A total of 318 observations were classified as fish species, 73 of which were ≥ 40 cm in length (Table 1). All fish observations were common carp or unidentifiable fish - none were believed to be *O. mykiss*. Common carp observations occurred mostly in low flow conditions < 50 cfs (93.4% of all observations, Table 2). Common carp were significantly more likely to be observed at night than during the day (t = 3.946, df = 20, p = 0.0004) with 59 observations during the day and 230 at night (Figure 5).

METHODS – REDD SURVEYS

Data Collection

Spawning ground surveys (redd surveys) were conducted in accordance with standardized protocols developed by CDFW Coastal Monitoring Program (CMP) scientists for use throughout California (Gallagher 2007, McLaughlin and Christianson 2016). Surveys were conducted from December 5, 2019 through May 27, 2020 in the Ventura River watershed consisting of 19 reaches encompassing 46.9 stream miles. Fourteen of the nineteen survey reaches occur in anadromous waters and compose 36.7 stream miles of potential spawning habitat. The five survey reaches removed from anadromy were included since they historically supported *O. mykiss* and are upstream of the Matilija Dam currently planned for removal.

Individual reach designations were determined by the sampling frame currently under development by CDFW CMP and Fisheries Branch biologists and mirror reaches used historically by the National Marine Fisheries Service. Reaches begin and ended at easily identifiable landmarks (e.g. bridges or accessible trails) and were designed to be completed in a single day. Surveys terminated at total barriers to anadromy and in one circumstance, lack of access due to private landowner.

Surveys were conducted every two weeks throughout the survey season when flows and weather permitted. Two weeks is the minimum amount of time redds remain detectable in southern California stream systems (R. Bush, National Marine Fisheries Service unpublished data, CDFW Ventura Basin LCM draft data). Teams of two to three surveyors walked reaches in an upstream direction recording redds, bankside *O.*

mykiss observations, and threatened and special status aquatic species on handheld data recorders. All fish observed were identified to species. For each *O. mykiss* observation, a total length (TL) estimate, location, and life history stage (when possible) were recorded.

When redds were first observed, measurements were taken for pot and tail spill dimensions. Pot length, width, and depth relative to the adjacent streambed were measures. For tail spill dimensions, tail spill length and width measurements were taken at 1/3 and 2/3 the distance from the upstream end of the tail spill as described in Gallagher 2007. Dominant substrate size was recorded for both the pot and tail spill. Redds were identified with a flag denoting the redd record number, distance, and bearing of the redd from the flag location, date the redd was first identified, and redd age. Redd ages were categorized as the following: 1 - New since last survey, 2 - Previously identified and still measurable, 3 - No longer measurable but still visible, and 4 - No redd apparent. Redd ages were updated and recorded during subsequent observations. Redds were re-measured when pot and tail spill dimensions had noticeably changed following their initial observation.

Data Analysis

The mean ± SE number of days between surveys was calculated to examine survey frequency. Water visibility was examined as a metric for redd detectability. Visibility measurements were classified as either “clear” (i.e., visibility = 100%) or “not clear” (visibility < 100%) for each survey. The mean ± SE number of surveys where visibility was 100% was calculated by reach and by watershed for each year.

Redd observations were mapped using ArcGIS 10.1 (ESRI, Redlands, California) and R Software (R Core Team. 2016). Area and total redd length for each redd were calculated. Redd area was calculated as the sum of pot and tail spill areas per Gallagher et al. (2007). Total redd length is calculated as the sum of the pot and tail spill lengths. Redd dimensions and area are used to compare the relative sizes of all redds observed and to indicate those produced by anadromous *O. mykiss*. Individual trout observations were mapped to demonstrate spatial distribution throughout the watershed as well as associations with habitat and fish size class.

To characterize any potential changes over time, we compared data collected from surveys conducted in the Ventura River in 2019 with data collected from 2013 through 2018 using one-way ANOVA. We also used post hoc analysis using Bonferroni’s adjust p values to test for differences between individual survey seasons. We examined redd counts, redd area, redd life (i.e., the duration of time redds remained detectable), *O. mykiss* bankside observation totals and visibility versus year for trends per Gallagher (2005). When evaluating redd and trout count data, comparisons were drawn from data where survey effort was consistent (i.e., years 2015 – 2019). Analyses of redd life by year were only performed for redds in years where a final status indicating that they were no longer visible (i.e., redd age 4) was recorded. All redds recorded from 2013 – 2019 were included in our examination of redd area versus year due to low sample size. Visibility comparisons were also drawn between all years from 2013 – 2018. All analyses were completed using R software.

RESULTS – REDD SURVEYS

A total of 147 redd surveys were conducted within the Ventura River watershed from December 5, 2019 to May 27, 2020 during the spawning season with a mean number of days between surveys of 19.47 ± 0.77 (SE, Table 3

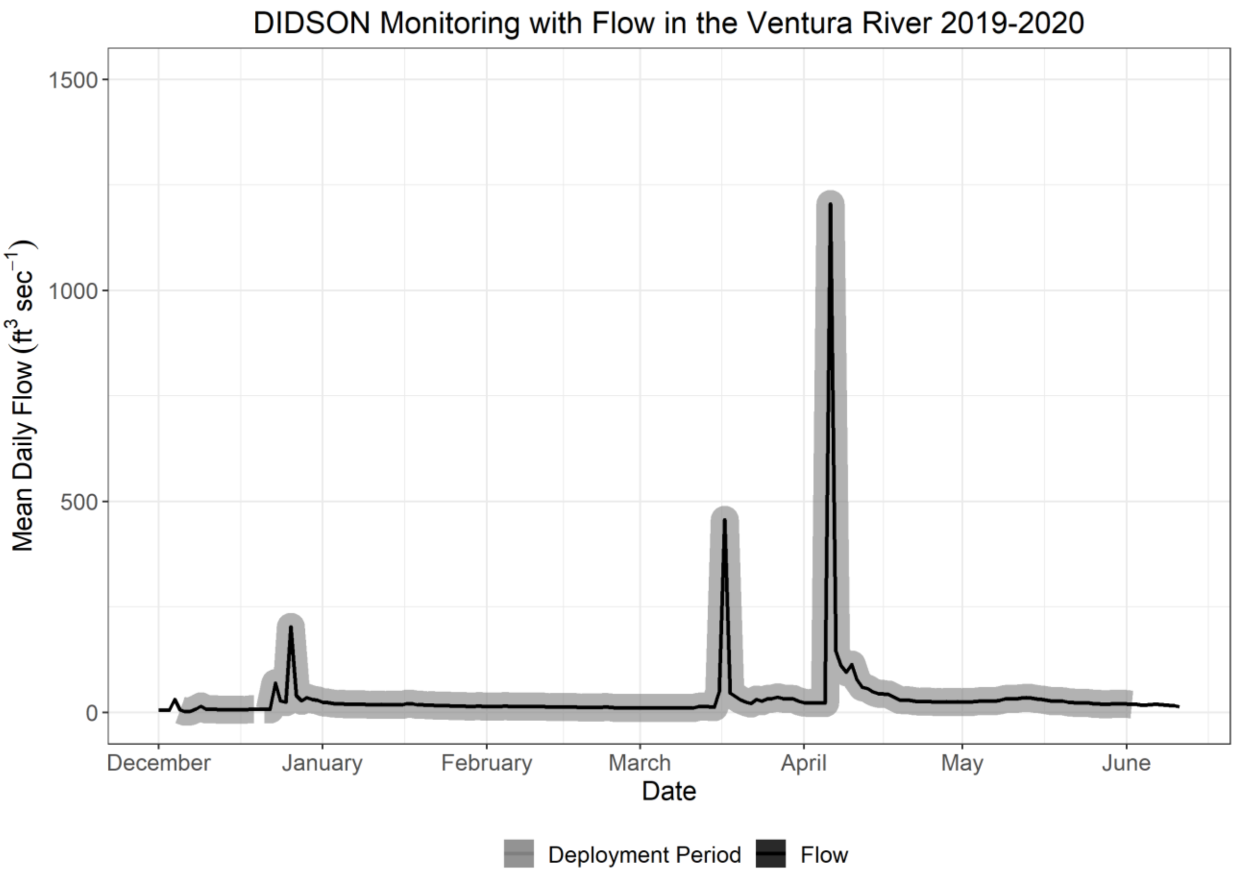

Figure 4: Ventura River stream flow plotted against time for 2020. Data was recorded by a standard DIDSON 300m camera operating in high frequency (1.8 Hz) deployed in the Ventura River from December 5, 2019 to June 2, 2020.

Table 1: Total species observations recorded on DIDSON deployed at each stream site (excludes "unknown" species and "Person" observations). Data was collected during the southern California steelhead spawning season from December 2019 to June 2020.

Species	**n**	**Observations ≥40 cm**
Common Carp	289	72
Crayfish	1	0
Frog	10	2
Snake	1	1
Turtle	12	0
Unidentified Fish	29	1
Unidentified Terrestrial	1	0
Waterfowl	24	0

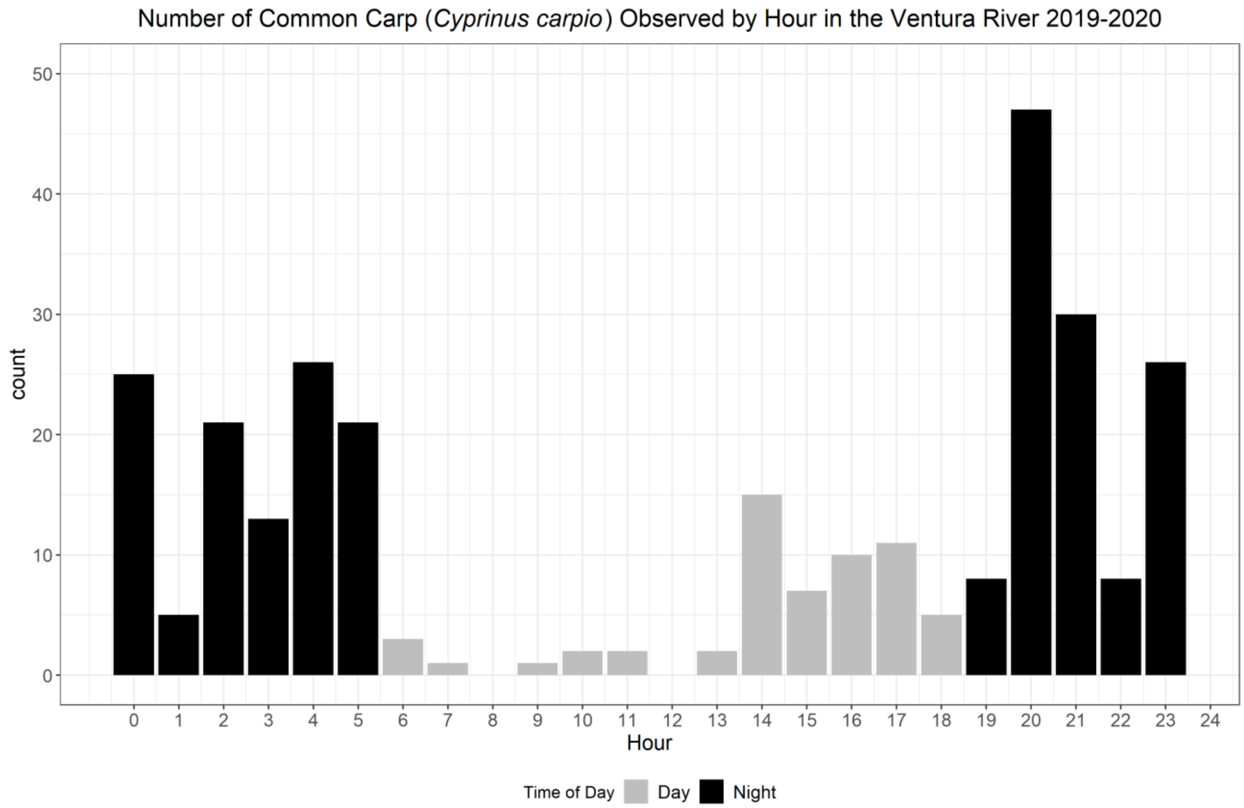

Figure 5: Common carp observations at the Ventura River DIDSON site by hour of the day (n = 59 day observations, 230 night observations), 2019-2020.

Table 2: Ventura River common carp observations binned by stream flow increments of 25 cfs, 2019-2020. Flow data was taken from a USGS stream gauge at Foster Park.

Flow Bin (cfs)	n	Percent of Observations	Cumulative Percent
0-25	139	48.1	48.1
25-50	131	45.3	93.4
50-75	5	1.7	95.1
75-100	1	0.3	95.4
>100	13	4.5	99.9

Table 3: Frequency of redd surveys within the Ventura River watershed, 2020.

). Water quality was mostly sufficient for redd surveys, with 86% of surveys completed with 100% visibility (Table 4).

Three redds were observed on Muriertta Creek on February 12th or February 25th 2020 (Figure 6). The mean redd area was 176.82 ± 61.16 in^2 with the smallest redd measuring 106.42 in^2 and the largest 298.65 in^2 (Table 5). Redd life ranged from 63 to 93 days with a mean life of 73 ± 10 days. A total of 43 bankside *O. mykiss* observations were documented, all of which occurred in Murietta Creek (Figure 7). Fish in the 6-8 in and 10-12 in size class were observed most frequently with 15 and 10 observations, respectively (Table 6). Other bankside observations of threatened or endangered species throughout the Ventura River watershed included California red-legged frog (*Rana draytonii*), two-striped garter snake (*Thamnophis hammondii*), and southern western pond turtle (*Actinemys pallida*, Table 7).

Multiyear Comparison

The three redds observed during the 2019-2020 season are the most since 2017, when 11 redds were documented. No redds were observed in 2018 and 2019. However, this is the first year Murietta Creek was included in redd surveys, and the number of redds documented in the rest of the Ventura River watershed was zero. Excluding 2018 and 2019, the three redds in 2020 are below the mean number of redds observed from 2013-2017 ($\bar{x}$ = 16.6 ± 3.5). Mean redd area in 2019-2020 (176.82 ± 61.16 in^2) was slightly smaller than mean redd area from 2013-2017, with overall average of 205.39 ± 11.28 in^2. None of the redds from 2013-2017 were believed to be from anadromous *O. mykiss*, so differences in size are not likely due to life history variation. Redd area was did not vary significantly between 2013 – 2020 in the Ventura River (ANOVA: f = 1.577; d.f. = 5; p = 0.18). Further, post hoc analysis using a pairwise t-test with Bonferroni adjusted alpha levels (α = 0.003) did not find any significant difference between any two individual years (all p values > 0.64) . 2018 and 2019 were excluded from analysis because no redds were observed in either year.

An analysis of variance showed there was a significant difference in estimated redd life by survey year from 2014 – 2017 in the Ventura River basin (ANOVA: f = 7.2, df = 4, 44; p < .001). Post hoc analysis using a pairwise t-test with Bonferroni adjusted alpha levels (α = .005) showed that estimated redd life in 2019-2020 varied significantly between years 2014 and 2017 (Table 8). 2013 was excluded from analysis because of uncertainty behind redd life estimates.

The number of *O. mykiss* bankside observations was less than the historic average; the mean number of observations from 2015 – 2017 was 281 ± 39 Ventura River watershed. The total number of *O. mykiss* bankside observations decreased by two orders of magnitude in 2018 (n = 2), dropped to zero in 2019, and increased to 43 observations in 2020. Again, this was the first year Murietta Creek was surveyed, so an overall increase in bankside observations does not truly reflect the overall *O. mykiss* population trend.

Spatial distribution of *O. mykiss* bankside observations across all years in the Ventura River (i.e., 2013 – 2019), show the majority of observations (94%) were recorded in the upper watershed (i.e., upstream of the confluence of North Fork Matilija Creek and Upper Matilija Creek). Redd observations recorded during the same timeframe exhibited a similar distribution pattern with 88% of redds being observed in the upper watershed. In 2019-2020, 100% of redds and bankside observations of *O. mykiss* were recorded in the upper watershed.

METHODS – PIT Tag Array

Data Collection

PIT Tagging

Using Smith-Root LR-24 backpack electrofishers crews conducted single pass electrofishing surveys along a 0.5 mi stretch beginning at the confluence of Murietta Creek and Matilija Creek on November 25th-26th 2019. This reach was selected for known presence of *O. mykiss* and quality fish habitat and is likely the only stream within the Ventura watershed to support a stable resident *O. mykiss* population that may possess the allele for anadromy (Clemento et al. 2009). Crews targeted deep water habitat units (mean depth > 1 ft) to maximize the number of fish captured and tagged. Before electrofishing unit temperature, dissolved oxygen (mg/L), and conductivity (mS/cm^3) were recorded to ensure conditions did not exceed recommended electrofishing levels according to NMFS (2000). Electrofisher settings for all units were 100-130 V, 30 Hz, and 30% duty cycle. Electrofishing technique for fish capture in each habitat unit followed protocols described in NMFS (2000).

Upon capture, all species were removed from the unit and placed in an aerated five-gallon buckets filled with stream water. Water in the buckets was refreshed at 15-minute intervals to ensure temperatures remained low. The number and species of each organism were recorded and returned to the unit following completion of electrofishing in the habitat unit.

Trout greater than 80 mm (fork length - FL) were injected with a 134.2 kHz half duplex (HDX) ISO PIT tag. Fish large enough to receive a PIT tag were placed one at a time into a bucket containing an anesthetic bath of effervescent antacid and stream water. Trout were monitored closely and removed from water for PIT tag injection when they began showing signs of equilibrium loss. PIT tags were injected using a sterilized syringe injector with the bevel facing down to avoid additional tissue damage (PTAGIS 2014). Trout less than 175 mm FL received 12 mm HDX PIT tags whereas trout larger than 175 mm received 23 mm HDX PIT tags. Immediately following tag injection, fish were placed in a new bucket with stream water and were monitored until they regained equilibrium and showed signs of normal swimming behavior. All tagged trout were released into the same habitat unit from where they were captured. Fin clips were taken from each PIT tagged *O. mykiss.* Samples are stored at the CDFW office in Santa Barbara and will be sent to Carlos Garza (NOAA, Santa Cruz, CA) for genetic analysis.

PIT Tag Reader Deployment

On December 3, 2019 a single-loop, pass-over, instream antenna was installed 15 ft downstream of the DIDSON camera site along the Ventura River mainstem (Figure 2). Marine 10-2 wire was passed through a 1-inch poly-vinyl chloride (PVC) frame that spanned the width of the stream channel was secured to the streambed with metal stakes and galvanized steel cables attached to Duckbill Earth anchors. The antenna was connected to a HDX Antenna tuner box (Oregon RFID) that was mounted onto a large metal pipe along the stream bank. An Oregon RFID HDX Marker Tag was fixed within the antenna read zone along the marine 10-2 wire between the tuner box and instream antenna. The Marker Tag includes a HDX PIT tag that is electromagnetically shielded and allowed to transmit on a set interval. During this interval the tag will be recorded by the antenna assuming proper operation. This creates a record of continuous antenna operation during extended deployments. From the tuner box, the 100-ohm twinaxial cable ran to the topside reader box (Multi-Antenna HDX Reader – Oregon RFID) that was enclosed in a Jobox security container. Power was supplied by a permanent, stable power source provided by the Ojai Sanitation District. A MC4 10 gauge solar cable connected the solar panel to a charge controller box within the security container that regulated discharge and recharge of two deep-cycle marine batteries.

A second PIT tag array was deployed on January 2, 2020 along San Antonio Creek at the East Old Creek Rd bridge crossing 0.51 mi upstream of the confluence of the Ventura River and San Antonio Creek (Figure 3). Electrical connections and general configuration was the same as the Ventura River PIT tag array, however, the set-up differed in that the tuner box was mounted on a studded T-post and power was supplied to the array via two 200W polycrystalline solar panels (model ZS-200-15AW) mounted on a four-foot pole. The solar panels supplied power to two deep cycle marine batteries via a charge controller. A 12-hour switch timer was used to alternate discharge and recharge of the two batteries. The JOBOX security container and solar panels were located above the flood prone area on the eastern bank near the base of the bridge. With landowner permission, the array was located on private property and hidden from street view to protect against vandalism.

Upon construction of the PIT tag readers, antennas were tuned to ensure that the frequency emitted by the antenna matched the frequency of the HDX PIT tags. Read range was also tested regularly to ensure tagged trout would not be able to evade detection. Weekly site checks were made to ensure the systems were intact and operating properly, and to download reader data. Adjustments to the tuning frequency

Data Analysis

Operational efficiency, PIT Tag detections, and descriptive statistics were calculated from detection logs recorded on the HDX readers. We report timing, direction of travel, and morphometric data at the time of tagging for each PIT tag detection. With sufficient PIT tagged adult returns ($n \geq 30$ fish), abundance estimation would be conducted following the T-JAMM design as described in Boughton et al. 2010.

RESULTS – PIT Tag Array

PIT Tagging

Nine *O. mykiss* were captured via electrofishing within 39 pool and deep-water habitats spanning a 0.5 mi section of Murietta Creek on November 25-26, 2019. Two trout were implanted with 12 mm HDX PIT Tags and seven with 23 mm HDX tags.

PIT Tag Array

A PIT tag array was deployed in the Ventura River from December 3, 2019 and was operational through June 2, 2020. The Ventura array experienced several bouts of technical failure with marker tag data missing from 40 of the 180 total deployment days, with an operational efficiency of 77.6%. Most of these technical failures occurred when the antenna fell out of tune or when electrical connections were damaged or dislodged by high stream flows.

A PIT tag array was deployed in San Antonio Creek from January 2 to June 2, 2020. Of the 150 days the PIT reader was deployed, it was fully operational for all but one three-hour period, resulting in an operational efficiency of 99.9%.

No upstream or downstream detections were recorded on either of the Ventura River Basin PIT Tag arrays during the 2019-2020 season. Since no fish have been tagged in anadromous waters in the Ventura River watershed and no detections were recorded on PIT tag arrays an abundance estimate for anadromous *O. mykiss* can not be produced at this time.

Multiyear Comparison

PIT tag arrays have been deployed in the Ventura River watershed since 2017; PIT tag arrays were installed in North Fork Matilija Creek in 2017 and 2018, in the mainstem Ventura River in 2018, 2019, and 2020, and in San Antonio Creek in 2020. Since the first deployment of a PIT tag array in 2017, readers have yet to record a detection of a tagged *O. mykiss*.

DISCUSSION

DIDSON

This project demonstrates the efficacy of sonar cameras for steelhead abundance monitoring in southern California streams. Operationally, we achieved high detection efficiency and read range despite challenging environmental conditions (e.g., high turbidity, high flow events, dynamic channel morphology, and fine sediment). This suggests that our closely reflect true steelhead abundance in focal streams, rather than a function of methodological limitations.

The lack of *O. mykiss* observations continues the near-zero trend since the start of DIDSON monitoring in the Ventura River with only one *O. mykiss* observation from DIDSON footage in 2019. Given the scarcity of southern California steelhead in these watersheds, the use of passive data collection methods that do not alter or otherwise negatively influence potential spawning activity (i.e., DIDSON), will likely remain at the forefront of preferred approaches to tracking adult abundance. Continued refinement of methods to differentiate between steelhead and non-target species and development of deployment methods that will allow sonar deployment during peak flows will be critical steps toward maximizing DIDSON and ARIS utility under southern California conditions.

Environmental Challenges

In previous years cameras were removed prior to large storm events to protect against loss or damage of equipment. Re-deployment would then be delayed until project personnel could safely work in and around the stream channel (approximately 200 cfs). This led to interruptions in data collection during the receding limb of the hydrograph when steelhead may migrate (McEwan 2001). To limit any potential observational bias imposed by stream flows additional security anchors were installed and the cameras remained deployed through all flow events in the 2020 winter season. In theory this would allow continuous data collection during flow events outside an initial loss in sonar range caused by a pulse in turbidity associated with rapidly increasing flows.

Elevated turbidity during peak flows partially limited sonar camera effectiveness. When turbidity reaches extreme levels (> 600 NTU) the sonar's range is reduced to < 1 meter (Santa Barbara Channel Keeper 2018). Image range would then gradually increase as suspended sediments settled out of the water column. These periods were brief (i.e., < 24 hours) and immediately followed peak flows. It is possible that *O. mykiss* could be missed during large flow events, but peak flows may limit the ability of *O. mykiss* to move upstream and more stable flows in the following days likely provide better conditions for migration. To the best of our knowledge, the limiting effects of turbidity on acoustic camera functionality are mostly unavoidable. Further understanding of the relationship between turbidity and sonar effectiveness is needed. To assess this relationship, continuous turbidity readings, collected concurrently with sonar deployments, are needed. These data can be compared with sonar imagery to establish standardized mathematical relationships between the two. This will allow for a quantifiable characterization of turbidity effects on sonar data collection and a better understanding of the implications for observational bias.

Prior to the Thomas Fire loss in sonar range associated with flow events ameliorated in the following 12-24 hours as described above. Increased sedimentation following the Thomas Fire in January 2018 have altered DIDSON operation as increases in fine sediment during high flow events have begun filling and clogging the camera housing blocking sonar image until such a time when staff could physically clean them out. As hills and banks continue to stabilize (+3-5 years post fire) we anticipate a reduction in the influence of fine sediment and a return to conditions outlined above driven by limitations in sonar technology.

Species Determination

The most considerable and well-documented challenge posed by DIDSON monitoring in project systems is species identification (Pipal et al. 2012, Burwen et al. 2007, Burwen et al. 2010). A number of methods have been suggested to address this problem, including the use of tail-beat frequencies (Mueller et al. 2010), acoustic shadows (Langkau et al. 2012), paired optical video system (Killam 2012), and trapping methods (Denton et al. 2015). The feasibility of each option is under review for southern California steelhead monitoring applications. The current means of differentiating between species in the Ventura River relies on evaluating swimming behavior and body morphology on a case-by-case basis. This method is problematic because it is subjective and depends heavily on reviewer experience.

In watersheds where species overlap in size with steelhead (e.g., *C. carpio* in the Ventura River), species determination remains a significant limitation in sonar technology. Although, in clear conditions and with proper reviewer training, *C. carpio* movement and body shape is usually sufficiently distinct from that of *O. mykiss.* When possible, operation of DIDSON cameras in watershed such as Topanga, which contain no fish species overlapping in size with steelhead, may remove limitations of species identification. Alternatively, a confirmation system such as paired PIT Tag or trap data or use of optical systems may assist species determination. These systems may also assist with identification of downstream smolts as they may be more difficult to identify with DIDSON.

Total *C. carpio* observations were similar to the 273 observed in 2019. Observations of *C. carpio* were also associated with low flow conditions in 2019, but a lower percentage of observations were observed during the day (51.4%) than in 2020 (25.7%). The data from 2020 and years prior to 2019 provide support of nocturnal activity and feeding in *C. carpio* (Bajer et al. 2010), perhaps suggesting 2019 was an outlier. Continued research of *C. carpio* detections and behavior may help elucidate the extent of interaction with *O. mykiss* in the Ventura River watershed.

Redd Surveys

Redd survey frequency slightly exceeded the recommended two-week frequency (average of 19.47 days) due to unsuitable stream conditions (e.g., high flow events, high turbidity, and low visibility) and staffing limitations incurred by COVID-19 safety regulations. The detection of three redds in Murietta Creek watershed suggest the presence of a stable, albeit small, population of resident *O. mykiss*. The Matilija Dam rules out any possibility that the redds observed belong to anadromous individuals. Without established estimates of detection probability in southern California, limited redd observations do not allow for reliable population estimations.

A long mean redd life (73 days) ensured that the two-week surveying period was sufficient to not miss redds due to degradation despite a 19.47 day survey frequency (Gallagher & Gallagher 2005). The long redd life estimates may suggest that substrate in Murietta Creek remains relatively stable during high flow events as redds were still detectable after a large rain event in March (Figure 8). Although, the small sample size and considerable temporal overlap of redd observations limit the ability to draw broad conclusions about stream conditions. It is unclear if rain events negatively impacted survival of eggs, alevins, and fry. No fish in the 0-2 in size class were documented among bankside observations which may suggest high alevin and fry mortality due to the significant rain event, although lower detection probability of smaller fish may bias bankside observations toward larger fish. Later season juvenile snorkel surveys may provide clarity.

Multiyear Comparisons

The 2019-2020 redd season revealed a continued trend of few redd and bankside *O. mykiss* observations. Although three redds are the most observed since 2017, they occurred in a stream reach that was not previously surveyed. While documentation of a small population of *O. mykiss* is beneficial for the species at large, the lack of detections in anadromous waters suggests a near-zero steelhead population in the Ventura River watershed.

That redd area did not differ significantly between 2019-2020 and previous years is expected – all previously recorded redds and redds observed this year were produced by resident *O. mykiss*. The relatively long redd life of redds in 2019-2020 may be due to the timing of rain events, protection from rain events in Murietta Creek, or both. Southern California streams are subject to flashy, high-flow events and the timing of rain events can abruptly destroy existing redds and threaten juvenile survival (Bell et al. 2012). Further, timing of high flow events may have contributed to lack of observations of 0-2 in fish in Murietta Creek.

PIT Tag Array

Deployment of the PIT tag arrays was successful as both arrays remained operational through significant storm flows without significant damage. Occasional adjustments to the frequency of the antenna were needed, but we were able to minimize times when the HDX reader was not reading properly. Inclusion of ATC-Auto Tuners (Oregon RFID) in future deployments will remove the need for manual tuning adjustments and should ensure continued antenna operation. Future monitoring will include the operation of a third antenna along North Fork Matilija Creek. Operation of all three sites will allow estimations of migrating speed and help identify high quality spawning habitat.

Significant numbers *O. mykiss* have not been tagged in anadromous waters in the Ventura watershed since 2008 (Scott Cooper; Casitas Municipal Water District personal communication) so a lack detections of migrating *O. mykiss* is not unexpected. Although *O. mykiss* were tagged in Murietta Creek this year, the Matilija Dam prevents downstream migration for these fish. Any *O. mykiss* detections would likely be a fish tagged in a nearby watershed that immigrated into the Ventura River. Tagging of *O. mykiss* within the Ventura River watershed will continue although currently populations only persist above total barriers to anadromy. Tagging efforts may factor into future detections following completion of ongoing restoration efforts.

Environmental Challenges

The damage or entanglement of instream equipment while working in flashy southern California steams remains a primary concern when operating PIT Tag antennas. A pass-over antenna design in which the antenna lays flat against the streambed, as opposed to pass-through antenna positioned perpendicular to the streambed, was selected based on flashy debris laden nature of storm flows and with proper anchoring, remained intact for the duration of deployment.

Tag read range at any point along the Ventura and San Antonio antennas was estimated at eight and 12 in for the 12 mm and 23 mm HDX tags, respectfully. HDX Pass-over designs are limited by this read range as portions of the water column may be outside the range in systems with great base flow depths or downstream tailwater controls. A pass-over was selected for the site in Ventura River and San Antonio Creek as water levels only exceed the pass-over read range depth (~1 ft) for extremely brief periods of time during peak flow events. As flows recede, the entire water column reenters the read range. Due to technological limitations (read range) there may an underestimation of downstream smolts by operating a pass-over antenna as they may to move downstream in the upper portion of the water column (Hartman 1967). However, this was not a concern this year since no tagged *O. mykiss* were present in anadromous waters. In future deployments of a pass-through antenna in proximity will help determine potential bias in current monitoring techniques.

The low profile of a pass-over design, secured to the streambed with earth anchors, metal stakes, and airline cable make it ideal for flashy debris laden storm flows experienced in the Ventura watershed. While it is unclear if migrants moving during peak flows are being undercounted, it is our belief a pass-over design is best suited for these conditions. Pass-through arrays are more likely to be damaged during peak flows and we believe the continued operation of the array during receding flows provides more benefit than the added vertical range of the pass-through.

FIGURES & TABLES

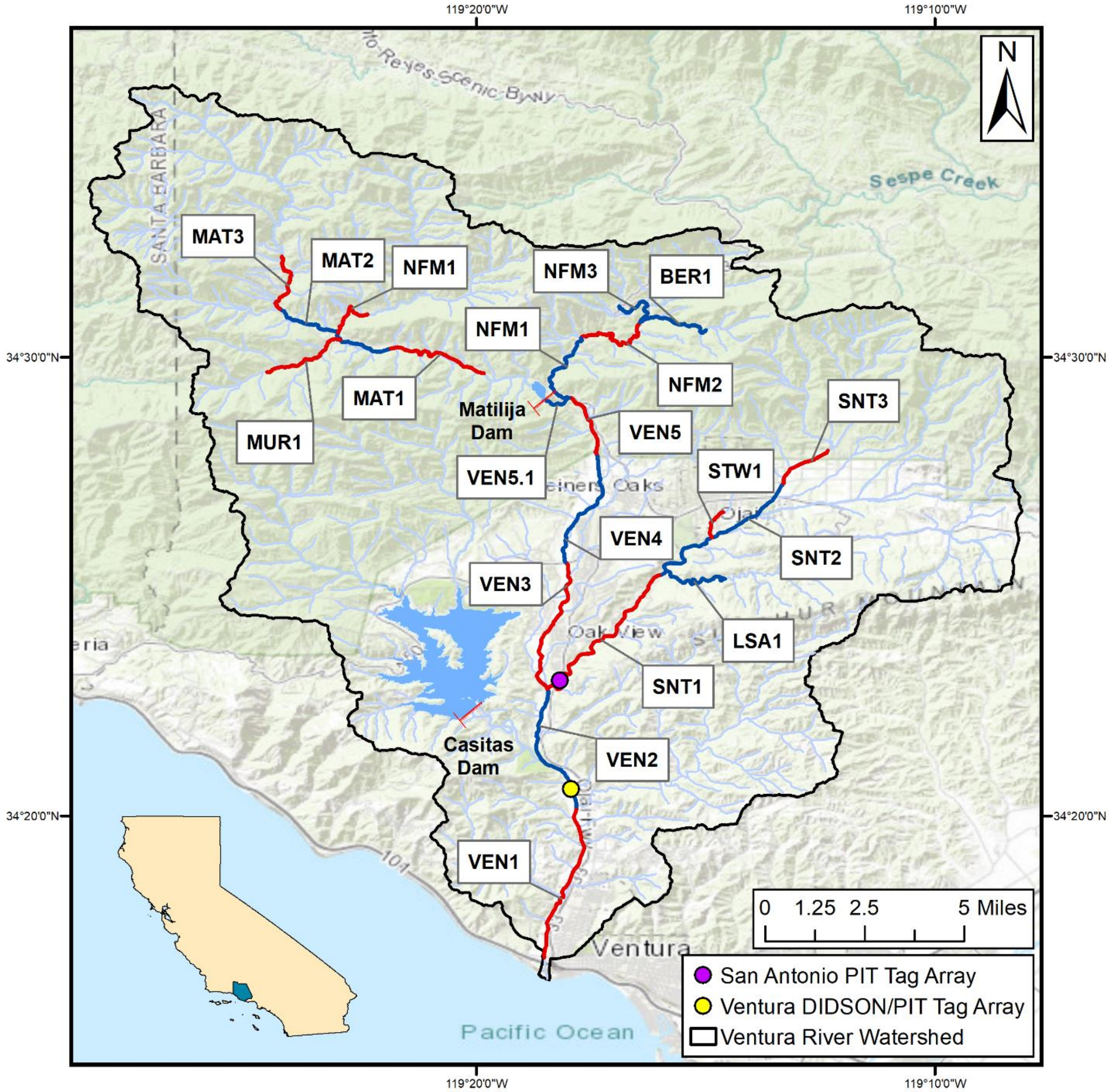

Figure 1: Overview of Ventura River watershed. Individual redd reaches are delineated as well as the location of the DIDSON and PIT tag array sites.

Figure 2: Ventura DIDSON and PIT tag array site. a) DIDSON and ARIS parallel configuration on river left with paneling upstream and downstream of cameras. b) View from stream bank showing the tuner box mounted to a large metal pole and the antenna on the streambed. c) View of the DIDSON and ARIS cameras during a high flow and turbidity event. d) View looking upstream at the PIT Tag antenna and DIDSON and ARIS cameras

Figure 3: San Antonio Creek PIT tag array. The top image shows the solar panel and topside reader box. The lower image (facing upstream) shows the antenna in the stream and the tuner box mounted on a post on river left.

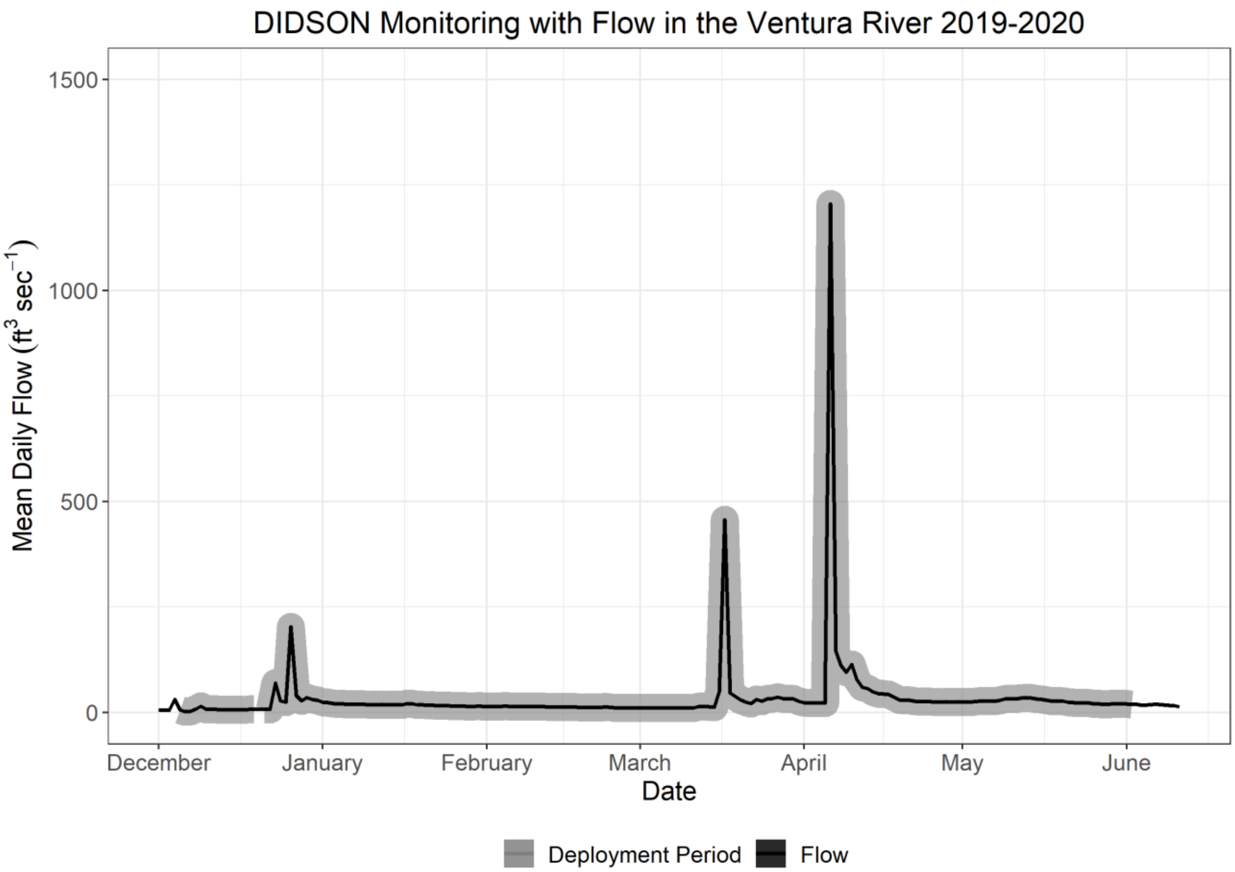

Figure 4: Ventura River stream flow plotted against time for 2020. Data was recorded by a standard DIDSON 300m camera operating in high frequency (1.8 Hz) deployed in the Ventura River from December 5, 2019 to June 2, 2020.

Table 1: Total species observations recorded on DIDSON deployed at each stream site (excludes "unknown" species and "Person" observations). Data was collected during the southern California steelhead spawning season from December 2019 to June 2020.

Species	n	Observations ≥40 cm
Common Carp	289	72
Crayfish	1	0
Frog	10	2
Snake	1	1
Turtle	12	0
Unidentified Fish	29	1
Unidentified Terrestrial	1	0
Waterfowl	24	0

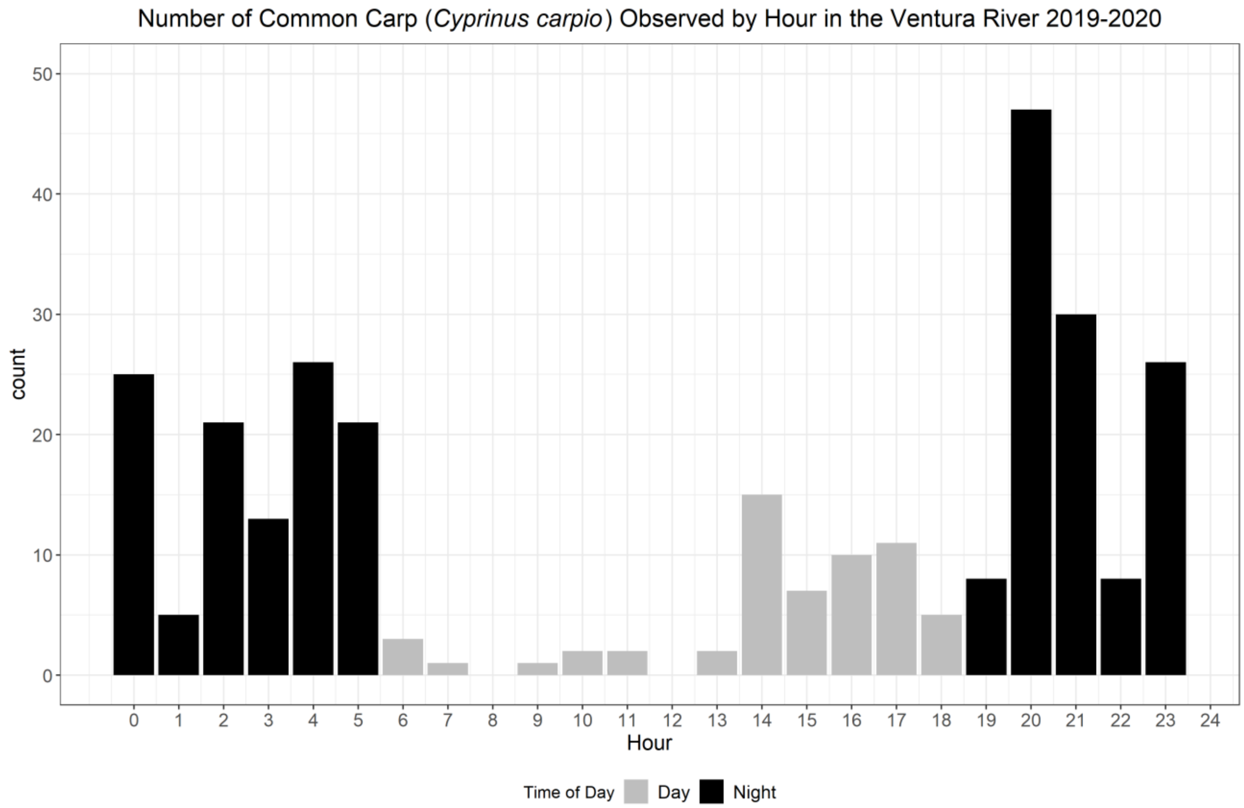

Figure 5: Common carp observations at the Ventura River DIDSON site by hour of the day (n = 59 day observations, 230 night observations), 2019-2020.

Table 2: Ventura River common carp observations binned by stream flow increments of 25 cfs, 2019-2020. Flow data was taken from a USGS stream gauge at Foster Park.

Flow Bin (cfs)	n	Percent of Observations	Cumulative Percent
0-25	139	48.1	48.1
25-50	131	45.3	93.4
50-75	5	1.7	95.1
75-100	1	0.3	95.4
>100	13	4.5	99.9

Table 3: Frequency of redd surveys within the Ventura River watershed, 2020.

Survey Reach	N	Mean Survey	SE
Bear Creek	5	27.25	3.25
Lion Creek	8	19.14	1.91
Matilija Creek 1	7	21.00	5.63
Matilija Creek 2	7	21.00	5.63
Matilija Creek 3	7	21.00	4.72
Murietta Creek	8	21.14	5.14
North Fork Matilija Creek 1	7	21.00	2.80
North Fork Matilija Creek 2	7	21.00	2.61
San Antonio Creek 1	9	13.88	2.48
San Antonio Creek 2	9	18.00	2.62
San Antonio Creek 3	8	19.14	2.65
Stewart Creek	8	19.14	1.92
Upper North Fork Matilija Creek	7	20.17	4.83
Ventura River 1	9	18.75	2.42
Ventura River 2	8	21.43	2.75
Ventura River 3	9	16.88	3.05
Ventura River 4	9	17.00	2.83
Ventura River 5	8	18.29	4.05
Ventura River 5.1	7	21.33	3.34
Total	147	19.47	0.77

Table 4: Summary of visibility during redd surveys in the Ventura River watershed, 2020.

Survey Reach	**Total Number of Surveys**	**Number of Clear Surveys**	**Percent Clear Surveys**
Bear Creek	5	5	100.00
Lion Creek	8	8	100.00
Matilija Creek 1	7	6	85.70
Matilija Creek 2	7	6	85.70
Matilija Creek 3	7	6	85.70
Murietta Creek	8	8	100.00
North Fork Matilija Creek 1	7	7	100.00
North Fork Matilija Creek 2	7	7	100.00
San Antonio Creek 1	9	9	100.00
San Antonio Creek 2	9	9	100.00
San Antonio Creek 3	8	7	87.50
Stewart Creek	8	8	100.00
Upper North Fork Matilija Creek	7	5	71.40
Ventura River 1	9	2	22.20
Ventura River 2	8	7	87.50
Ventura River 3	9	8	88.90
Ventura River 4	9	6	66.70
Ventura River 5	8	7	87.50
Ventura River 5.1	7	6	85.70
Total	147	127	86.00

Figure 6: Observed redds (N=3) from the 2019-2020 redd surveys. All redds were discovered in Murietta Creek.

Figure 7: Location of bankside *O. mykiss* observations from 2019-2020 redd surveys (N = 43). All observations were recorded in Murietta Creek.

Table 5*:*Mean redd dimensions for redds detected during the 2019-2020 spawning season in the Ventura River watershed (N = 3). All redds were observed in Murietta Creek.

Measurement	**Mean (in)**	**SE**
Pot Depth	1.71	0.35
Pot Length	10.50	0.86
Pot Substrate	1.51	0.46
Pot Width	10.63	2.02
Tail Spill Length	11.42	2.46
Tail Spill Substrate	0.50	0.10
Tail Spill Width 1	9.06	2.58
Tail Spill Width 2	4.33	1.49
Total Length	21.92	1.57
Total Redd Area	38.25 (in^2)	19.36 (in^2)

Table 6: *O. mykiss* bankside observations during redd surveys within the Ventura River watershed, 2020.

	Number of O. mykiss Observations Per Size Class						
Reach	0 – 2”	2 – 4”	4 – 6”	6 – 8”	8 – 10”	10 – 12”	**Total**
Murietta Creek	0	5	8	15	5	10	**43**

Table 7: Threatened and endangered aquatic vertebrate observations detected during redd surveys in the Ventura River watershed, 2019-2020.

Species	**Number Observed**
California red-legged frog (*Rana draytonii*)	15
Coastal rainbow/steelhead trout (*Onchorhynchus mykiss*)	44
Southern western pond turtle (*Actinemys pallida*)	19
Two-striped garter snake (*Thamnophis hammondii*)	9

Table 8: Pairwise t test comparison of mean redd life between survey years using Bonferroni adjusted alpha levels (α = 0.005). Significant differences are bolded. 2013 was excluded due to uncertainty of redd ages. No redds were observed in 2018 or 2019.

Year	**2014**	**2015**	**2016**	**2017**
2015	0.115	-	-	-
2016	1.0000	1.0000	-	-
2017	1.0000	**0.0011**	0.0781-	-
2020	**0.0196**	0.8380	0.1063	**0.0008**

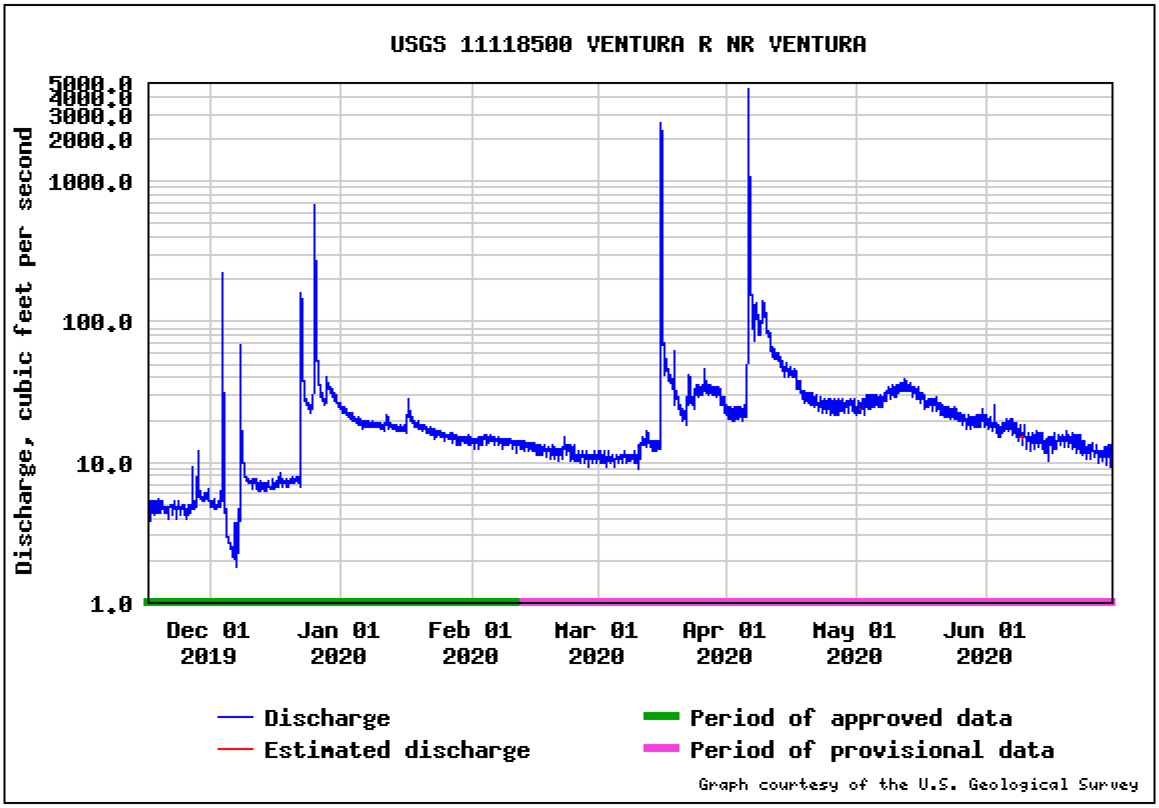

Figure 8: Stream discharge for Ventura River during the 2019-2020 redd season (Figure from USGS stream gauge near Foster Park, Ventura).

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