Sonar monitoring of southern California steelhead in Santa Barbara and Ventura Counties: 2016 - 2018

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ABSTRACT

Unbiased counts of anadromous adult *Oncorhynchus mykiss* are needed to assess abundance for federally endangered southern California populations. Sonar cameras are a reliable method of obtaining adult counts in southern California systems because they are able to collect data at night and under dynamic stream conditions (Adams et al. 2011). Sonar cameras were deployed in watersheds assigned a high priority for recovery action in Santa Barbara and Ventura Counties during winter spawning seasons in 2017 and 2018. Sonar footage was analyzed for observations of targets ≥ 30 cm in 2017 and ≥ 40 cm in 2018. Every observation was measured for length and classified to species. In 2017, 225 days of footage were acquired through deployments in Salsipuedes Creek, Carpinteria Creek and the Ventura River. Detection efficiency was consistently high across all deployments in 2017. In Salsipuedes Creek, 62 observations of targets ≥ 30 cm were recorded, none were recorded in Carpinteria Creek and 26,389 were recorded at the Ventura River site. Two observations in Salsipuedes Creek were designated as *O. mykiss* and measured 33 cm and 38 cm respectively. Both trout were observed swimming upstream and neither were seen returning downstream. No *O. mykiss* were recorded in the Ventura River; however, a considerable 26,344 observations of Common Carp *Cyprinus carpio* were recorded. In 2018, 109 days of sonar footage were acquired through deployments in Arroyo Hondo Creek and in the Ventura River. Detection efficiencies remained high throughout the data collection season. No observations ≥ 40 cm were observed in Arroyo Hondo Creek. For the Ventura River, there were 4,167 observations. Common Carp comprised the majority of these observations (n = 4,156). Four observations were classified as Pacific Lamprey (two upstream and two downstream). Common Carp data were further analyzed to explore means of differentiating between Carp and *O. mykiss*. This included examining differences in swimming motion, morphological features, and effects of environmental conditions (e.g. stream flow) on behavioral patterns. Carp detections per hour increased during night hours and were negatively associated with stream flow. Overall, this project demonstrates the efficacy of sonar cameras for steelhead abundance monitoring in southern California streams. Continued refinement of deployment methods are recommended for maximizing DIDSON utility in southern California conditions.

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 have been 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). The California Department of Fish and Wildlife has developed a framework to implement monitoring to track recovery progress (i.e., Fish Bulletin 180) (Adams et al. 2011). This framework is based on assessment of four viability metrics (i.e., Viable Salmonid Population parameters) comprised of abundance, productivity, spatial structure, and diversity (McElhany 2000, NMFS 2016).

To assess abundance for populations encompassed by the DPS, unbiased estimates of anadromous adults are required (NMFS 2016). Fish Bulletin 180 suggests the use of sonar cameras (i.e., DIDSON) to collect counts of anadromous adults in focal streams. Developed by Sound Metrics, DIDSON produces near video-quality imagery and allows for data collection night and during periods of high flow and turbidity (Sound Metrics 2018). These conditions are commonplace in southern California where flows are highly episodic resulting 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).

This report summarizes the methodologies and findings of sonar deployment, data collection, and data analysis efforts in four watersheds located in Santa Barbara and Ventura counties. These watersheds, with the exception of Arroyo Hondo Creek, were designated in the southern California steelhead recovery plan as being the first focus for recovery action (NMFS 2012) Findings will aid in the development southern California specific DIDSON monitoring protocols, and will inform resource managers on the status of steelhead populations in these high priority systems.

Study Sites

Salsipuedes Creek

Salsipuedes Creek is located southeast of the city of Lompoc in Santa Barbara County, California (Figure 1). It is the largest tributary to the lower Santa Ynez River and drains approximately 47.1 square miles (Santa Ynez River Technical Advisory Committee 2000). Salsipuedes Creek is 10 miles long, and its confluence with the Santa Ynez River is 16 stream miles from the Pacific Ocean. The deployment site is located 0.6 stream miles upstream of the confluence.

The Santa Ynez River main stem exhibits intermittent flow and drying during the spring and summer. Winter flows and connectivity to the ocean are highly dependent on precipitation. Intense and short-lived winter storms typically generate flows that connect Salsipuedes Creek with the Santa Ynez River. A large sand bar keeps the river mouth closed outside of high winter flows.

The areas of the Santa Ynez River watershed accessible to steelhead are home to a number of native and invasive fish species. The native fish species present include Threespine Stickleback (*Gasterosteus aculeatus*), Prickly Sculpin (*Cottus asper*), Pacific Lamprey (*Lampetra tridentate*), Arroyo Chub (*Gila orcutti*) and Tidewater Goby (*Eucyclogobius newberryi*) (Santa Ynez River Technical Advisory Committee 2000). The invasive fish species present consist of Fathead Minnow (*Pimephales promelas*), Mosquitofish (*Gambusia affinis*), Smallmouth Bass (*Micropterus dolomieui*), Largemouth Bass (*Micropterus salmoides*), Bluegill (*Lepomis macrochirus*), Green Sunfish (*Lepomis cyanellus*), Redear Sunfish (*Lepomis microlophus*), Black Crappie (*Pomoxis nigromaculatus*), Channel Catfish (*Ictalurus punctatus*), Black Bullhead (*Ameiurus melas*), Goldfish (*Carassius auratus*), and Common Carp (*Cyprinus carpio*) (Santa Ynez River Technical Advisory Committee 2000).

The Salsipuedes Creek site was chosen for its channel morphology, the availability of electrical power, and high level of security. The channel is trapezoidal in profile and allows for complete ensonification of the streambed. The stream bottom substrate is uniform, which allows for an unobstructed field of view. Site power is provided by a mobile solar trailer and battery bank. The site is located on private property and accessed via a gated, private road offering a high-level of site security. The DIDSON is located immediately downstream of a migrant trap operated by the Cachuma Operation and Maintenance Board allowing for comparisons between DIDSON and trap data.

Arroyo Hondo Creek

Arroyo Hondo Creek is located along the Conception Coast, 30 miles west of Santa Barbara, California (Figure 1). The watershed drains an area of 4.4 square miles and contains 4 miles of anadromous waters (Choi et al. 2002). Arroyo Hondo is a relatively small watershed, but has supported small runs of anadromous adult *O. mykiss* in 2016 and 2017 (CDFW unpublished data). A DIDSON was deployed in 2018 to increase understanding of the migration patterns and morphological characteristics for winter run anadromous adults.

The only species of fish that inhabit Arroyo Hondo Creek are *O. mykiss* and Tidewater Goby (*Eucyclogobius newberryi*) which only occur in the lagoon.

The DIDSON deployment site is 0.3 miles from the mouth of the creek. It was chosen for its close proximity to the Pacific Ocean, access to a reliable power source, trapezoidal channel profile, uniform bottom substrate, and high degree of security.

Carpinteria Creek

Carpinteria Creek flows through the city of Carpinteria located in Santa Barbara County, California (Figure 1). It drains 17 square miles and contains 7 miles of anadromous waters. The deployment site is located two miles upstream of the Pacific Ocean.

Extensive sections of the main stem regularly go dry in the spring and summer, serving primarily as a migration corridor to perennial, upper reaches (Cachuma Conservation District and the Carpinteria Creek Watershed Coalition 2005). Connectivity from the upper watershed to the ocean is highly dependent on rainfall and limited to periods following storm flows (Cachuma Conservation District and the Carpinteria Creek Watershed Coalition 2005). A seasonal sand bar restricts access to the creek until displaced by rising flows.

The areas of the Carpinteria Creek watershed accessible to steelhead are home to a small number of native fish species comprised of Threespine Stickleback (*Gasterosteus aculeatus*), Prickly Sculpin (*Cottus asper*), Pacific Lamprey (*Lampetra tridentate*), and Tidewater Goby (*Eucyclogobius newberryi*) (Padre and Associates Inc. 2002, Ecology Consultants 2003).

The channel profile and substrate allow for full ensonification of the stream channel. The deployment site is located along a seasonally wetted, migration corridor, which limits the potential for milling behavior. The site is located on U.S. Forest Service property in close proximity to firefighting personnel residences. As a result, the site is relatively secure. An extension cord running to an adjacent residence provides power.

Ventura River

The Ventura River flows through the cities of Ojai, Casitas Springs, and Ventura in Ventura County, California. The Ventura River drains 227 square miles and contains 35 miles of anadromous waters (California Department of Forestry and Fire Protection 1999). The 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 intermittent flows and drying over spring and summer. A seasonal sandbar 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 short periods.

Areas of the Ventura River accessible to anadromous adult *O. mykiss* are inhabited by a number of native and invasive fish species. Native fish species consist of Threespine Stickleback (*Gasterosteus aculeatus*)*,* Prickly Sculpin (*Cottus asper*), Pacific Lamprey (*Lampetra tridentate*) and 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*), and Largemouth Bass (*Micropterus salmoides*).

This site's channel profile and substrate composition allow unobstructed views of the full stream channel. The site is located on property owned and operated by the Ojai Valley Sanitation District. The storage container, from which cameras are operated, is situated within a perimeter fence and behind two locked, electronic gates.

METHODS AND MATERIALS

Data Collection

Sonar cameras were deployed at study sites once water depth exceeded six inches and continuous surface flow was established between the site and the ocean. Sonar cameras remained deployed as long as conditions allowed for fish migration from the ocean to the monitoring site. Prior to large forecasted storm events, cameras were removed to prevent loss of, or damage, to equipment. Cameras were re-deployed once personnel could safely work in the stream channel. In larger watersheds (i.e., the Santa Ynez River and the Ventura River), cameras remained deployed following river mouth closures to allow time for any fish that had entered the system time to migrate to monitoring sites.

Salsipuedes Creek

2017

A standard DIDSON unit (Sound Metrics, Lake Forest Park, Washington) operating in high frequency mode (1.8 MHz) was used in Salsipuedes Creek from January 23, 2017 to April 24, 2017.The camera was mounted to a track system so that it could be moved up and down the bank during high flows. The camera was housed in a silt box to keep sediment clear of the lens and attached to an X2 pan and tilt rotator (Sound Metrics, Lake Forest Park, Washington) to aim the camera remotely. The rotator was mounted to an aluminum sled and placed on the track. Willow stake baffles were installed upstream and downstream of the camera to prevent targets from passing too close (< 1 m) to be seen clearly. The camera was aimed perpendicular to flow and lowered as close to the stream bottom as possible while still maintaining a full field of view. This was done under the assumption that migrating steelhead will swim close to take advantage of decreased water velocity (Quinn 2005) and to prevent damage from floating debris.

The camera was connected to the topside control box by a 60 m DIDSON sonar cable. The topside box was connected to a Dell Toughbook running DIDSON software, to interface with the camera and adjust record settings. Focus and frame rate were set automatically by the software. Receiver gain was left at the default maximum value. Window length was set to 10 m for all deployments to ensure full channel coverage. Footage was captured in 20-minute files and written directly to an external hard drive. This was done to limit loss of data in the event of a file being lost or becoming corrupted per Pipal et al. (2010). Support electronics and components were held in a locked, mobile solar trailer located safely outside the floodplain as suggested by Pipal et al. (2010). Site visits were conducted on a regular basis to optimize camera settings in accordance with stream conditions and to exchange hard drives as needed.

Flow data for the Salsipuedes Creek site were obtained from a U.S. Geological Survey (USGS) stream gauge located 2.9 miles upstream of the DIDSON site. The proximity and lack of any substantial flow inputs between the DIDSON site and flow gage, make this a reasonable approximation of flow at the deployment site.

Carpinteria Creek

2017

A long-range DIDSON 300 m unit (Sound Metrics, Lake Forest Park, Washington) operating in high frequency mode (1.2 MHz) was used for all deployments in Carpinteria Creek from January 20, 2017 to March 23, 2017. The camera was housed in a Sound Metrics manufactured silt box to prevent lens fouling and a custom aluminum box to prevent damage by floating debris. The aluminum box was secured with a heavy-duty padlock. The camera was attached to a steel, sled foot A- frame mount using a RAM double socket ball joint as described by Larson (2013). The sled was held in place by gravel bags placed on the sled feet and by an aircraft cable tether running from the housing's padlock to a large nearby tree. The cable provided a safeguard against theft and prevented equipment from being swept away. The mount was flanked by native cobble berms to direct fish to an appropriate range and to prevent fish from passing behind the camera. The camera was positioned perpendicular to flow and set at as close to the bottom as possible while still fully ensonifying the channel. This was necessary to accommodate consistently shallow water depth (i.e., $\leq$ 0.6 m).

The DIDSON was connected to a topside control box via a 60 m DIDSON cable. The topside box was connected to a Dell Toughbook laptop to interface with the camera and adjust settings. Focus and frame rate were set automatically by the software based on camera settings. Gain was left at the default maximum value. Window length was set to 5 m for all deployments, which was reflective of the narrow channel width. Footage was captured in 20-minute files written to an external hard drive. All support electronics were powered by an uninterruptible power source (UPS) to provide short-term battery back up in the event of brief power outages. The UPS was powered by an adjacent private residence via an extension cord. Support electronics and components were held in a locked, weatherproof job box located outside the flood plain. Site visits were conducted on a daily basis throughout deployment to ensure proper camera operation under continually changing conditions.

Flow data for the Carpinteria Creek site were obtained from a U.S. Geological Survey (USGS) stream gauge located 0.3 miles upstream of the DIDSON site. The proximity, and lack of any substantial flow inputs between the DIDSON site and flow gage, make this a reasonable estimate of flow at the deployment site.

Ventura River

2017

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 used for all deployments in the Ventura River from January 18, 2017 through May 30, 2017. Cameras were deployed in parallel to compare functionality under southern California stream conditions. The DIDSON was mounted on an A-frame as described for Carpinteria Creek. 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. The AR2 was then affixed to an A-frame mount. Both A-frames were held in place by gravel bags placed on their sled feet and by tethers running from the A-frames to adjacent t-posts anchored 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 to an optimal imaging range.

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 respectively to interface with the camera and adjust record settings. Dell Toughbook laptops were used to run DIDSON and ARIS software. 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 UPS's connected to permanent onsite power. Site visits were conducted on a daily basis 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.

2018

A standard DIDSON 300 m unit (Sound Metrics, Lake Forest Park, Washington), operating in high frequency mode (1.8 MHz), was used for deployments in the Ventura River from January 29, 2017 through May 24, 2018. An ARIS 3000 unit, operating in high frequency mode, was deployed in the Ventura River from March 3 through March 19. DIDSON and ARIS installation was completed following methods described for 2017. A second DIDSON camera was installed from April 19 to May 24. This camera was placed in parallel to the first, following previously described methods, but with the camera tilted 90 degrees on its vertical axis. This was accomplished by putting one side of the a-frame mount on the stream bottom (Figure 5). Arranging the DIDSON in this way provides an alternate view (i.e., side vs. top down) of targets and allows for better resolution of key morphological features (e.g. fin shape and body depth) used to differentiate between fish species.

Site visits were conducted on a daily basis to ensure proper camera operation. Prior to removing the cameras, 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 were obtained as described for 2017.

Arroyo Hondo Creek

2018

An ARIS Explorer 3000 (Sound Metrics, Lake Forest Park, Washington) operating in high frequency mode (3.0 MHz respectively) was used for all sonar data collection in Arroyo Hondo Creek from March 25, 2018 to April 26, 2018. The methods for ARIS setup and configuration in Arroyo Hondo followed those used in 2017 Ventura River operations.

The camera was positioned facing perpendicular to flow as close to the stream bottom as possible while still fully ensonifying the stream channel. The ARIS assembly was flanked by cobble berms to direct fish to an appropriate imaging range and to prevent fish passage behind the camera.

The ARIS was connected to control components, and software settings were adjusted as described for Ventura River ARIS operations. All electronics and support components were held in a locked, weatherproof job box located outside the flood plain. Site visits were conducted on a daily basis to optimize software settings and camera positioning and to change out external hard drives as needed.

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 30 cm in length were recorded in 2017. This was increased to 40 cm in 2018, which was considered the minimum size needed to assign species, and corresponds with the California Department of Fish and Wildlife's listed lower size limit for steelhead of 40 cm (California Department of Fish and Wildlife 2017).

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 designates 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.

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.

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

Sonar observation counts were summarized by site and species each year. For anadromous *O. mykiss* observations, net movement would be 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 (i.e., Common Carp and Pacific Lamprey) have the potential to be misidentified as steelhead due to the overlap in spatial distribution, temporal cycles and range in typical adult lengths. To learn more about these species, and how they may be may be differentiated from steelhead; additional analyses were done for Common Carp and Pacific Lamprey observations in the Ventura River. These observations were compared with synchronous flow data to explore the effect of flow on movement patterns. 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 for Common Carp > 40 cm and the mean daily count of Common Carp were compared between 2017 and 2018 to evaluate change. Daily count data were log transformed before comparing mean daily counts across years. All analyses were completed using R software.

RESULTS

2017

A combined total of 225 days of sonar footage were recorded from January 18, 2017 to May 30, 2017 through deployments in Salsipuedes Creek, Carpinteria Creek and the Ventura River. Above average rainfall sustained elevated surface flows and provided prolonged opportunities for steelhead migration. Sonar cameras were removed prior to storms forecast to produce high flows in order to prevent loss or damage to equipment. Storm flows altered channel profiles at all sites and required adaption of camera placement, aiming and settings. Brief power outages and software malfunctions had minimal effects on operational efficiency (Table 1). Detection efficiency was consistently high, with the exception of short periods when extreme turbidity limited sonar range.

Salsipuedes Creek

Seventy days of sonar footage were recorded in Salsipuedes Creek over the course of three deployments in 2017 (Table 1). Sixty-two observations of targets measuring greater than or equal to 30 cm were recorded. Of these observations, two were designated as *O. mykiss* based on body shape, size and swimming motion. The remaining observations were classified as either Beaver (n = 4), Frog (n = 11), Snake (n = 16), Turtle (n = 6), Waterfowl (n = 17), Unknown terrestrial species (n = 9) or Unknown (n = 1).

The first *O. mykiss* was observed on February 26, 2017 at 0410 swimming upstream and measured 33 cm in length. The second was seen swimming upstream on March 13, 2017 at 1840 swimming upstream and measured 38 cm. Neither fish was observed returning downstream.

Carpinteria Creek

A season total of 37 days of sonar footage were recorded in Carpinteria Creek over the course of five deployments. No observations of targets greater than or equal to 30 cm were recorded.

Ventura River

A season total of 123 days of sonar footage were recorded in the Ventura River over the course of three deployments. A total of 26,389 observations measuring greater than or equal to 30 cm were recorded. Of these observations, 26,351 were identified as Common Carp *Cyprinus carpio* with the remaining 38 observations being classified as either Frog (n = 7), Turtle (n = 1), Waterfowl (n = 26) or Unknown (n = 4).

The mean $\pm$ SE length for *C. carpio* was 45.68 $\pm$ 0.05 and a substantial 20,625 of Carp observed exceeded the expected minimum steelhead length of 40 cm. Significantly fewer *C. carpio* were detected per hour during the day (i.e., 0600 – 1800) (835.1 $\pm$ 86.6 [mean $\pm$ SE]) than at night (i.e., 1800 – 0600) (1235.8 $\pm$ 71.9 [mean $\pm$ SE]) (Student's $t = -3.48$, d.f. = 22, $p < 0.01$). The majority of Carp detections (> 97 %) occurred under relatively low flow (i.e., < 60 ft^3s^{-1}) conditions (Table 3).

2018

A large-scale wildfire, the Thomas Fire, greatly influenced data collection efforts in 2018. The Thomas Fire burned 281,893 acres (InciWeb 2018, Figure 1) which included substantial portions of the Carpinteria Creek and Ventura River watersheds (Klose 2018). A high intensity rain event following the fire lead to widespread flooding and debris flows resulting in road closures. This restricted access to monitoring sites in Carpinteria Creek and the Ventura River in January and February. The large amount of sediment mobilized by post-fire rain events in the Carpinteria Creek watershed prevented sonar data collection in 2018. The sand bar at the mouth of the Santa Ynez River was not breached in 2018; subsequently DIDSON data was not collected at Salsipuedes Creek.

Arroyo Hondo

Thirty-two days of sonar footage were recorded at Arroyo Hondo Creek from March 25, 2018 to April 26, 2018 (Table 2). Image quality was consistently high and detection efficiency remained at 100% for the duration of the data collection season. Small (i.e., < 30 cm) *O. mykiss* and California Newts (*Taricha torosa*) were regularly observed, but no observations of targets ≥ 40 cm were recorded.

Ventura River

Seventy-seven days of sonar footage were recorded at the Ventura River site from March 3, 2018 to May 24, 2018 (Table 2). Detection efficiency remained high ($\geq 98\%$) across all deployments. Cameras were removed to avoid peak forecasted flows from March 18, 2018 to March 23, 2018 (Figure 10). A total of 4,167 observations of targets ≥ 40 cm in length were recorded. Of these observations, 4,156 were identified as Common Carp, 7 were classified as Frogs and the remaining 4 (2 upstream and 2 downstream) were identified as Pacific Lamprey.

The majority ($> 99\%$) of Common Carp observations occurred under relatively low flow conditions (≤ 40 ft^3s^{-1}) (Table 4). Both observations of Pacific Lamprey migrating upstream occurred during a period of elevated (> 46 ft^3s^{-1}) flow (Figure 11). Observations of Pacific Lamprey swimming downstream (n =2) exhibited less distinctive swimming behavior due to the decreased effort needed to swim in the direction of flow, but were still easily identifiable. The mean $\pm$ SE length for Pacific Lamprey was 52.54 ± 4.08.

For Common Carp ≥ 40 cm, the mean $\pm$ SE length was 46.84 ± 0.05. This was significantly less than in the mean length for Common Carp > 40 cm in length observed in 2017 ((48.6 ± 0.3 [mean $\pm$ SE]) (Student's $t = 5.04$, d.f. = 192, $p < 0.01$).

The number of Common Carp detections per hour was significantly less during daylight hours (i.e., 0600 – 1800) than during the night (Student's $t = -5.23$, d.f. = 22, $p < 0.01$). Significantly fewer Common Carp ≥ 40 cm in length were observed per day in 2018 (56.5 ± 5.3 [mean $\pm$ SE]) than in 2017 (179 ± 20.4 [mean $\pm$ SE]) (Welch's $t = 26.39$, d.f. = 8682.7, $p < 0.01$).

DISCUSSION

This project demonstrates the efficacy of sonar cameras for steelhead abundance monitoring in southern California streams. While no *O. mykiss* exceeding 40 cm were observed, detection efficiency remained consistently high across all deployments despite challenging environmental conditions (e.g., high turbidity, high flow, and dynamic channel morphology). This suggests that our findings are reflective of true steelhead abundance in focal streams, rather than a function of methodological limitations. 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 and ARIS), 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 some cases, sonar cameras were not put into operation despite conditions favorable for steelhead migration. This took place when storms were forecast to produce flows capable of damaging or sweeping equipment away. Decisions regarding deployment timing were dependent on current conditions (e.g., flow, soil saturation, fish passage potential) and projected rainfall totals. The decision making process was further complicated following the Thomas Fire and subsequent mud and debris flows. These events raised concerns over the mobilization of large amounts of burn material and soils from areas destabilized by the fire and rain. In several cases, storms underperformed and flow responses did not reach hazardous levels; however, re-deployment had to be delayed until project personnel could safely work in and around the stream channel. This lead to interruptions in data collection during high flows when steelhead may migrate (McEwan 2001). Any missed observations of anadromous adults would have a major impact on yearly abundance estimates due to the rarity of their occurrence. To limit any potential observational bias imposed by stream flows, methods for improved anchoring and stabilization of camera mounts must be implemented. This will be a critical step towards ensuring that sonar counts provide an unbiased estimate of adult abundance.

Turbidity was another factor that limited sonar camera effectiveness. When turbidity reached extreme levels (> 400 NTU) the sonar's range dropped 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., < 48 hours) and followed peak flows. To the best of our knowledge, the limiting effects of turbidity on acoustic camera functionality are unavoidable. Given that elevated sedimentation rates will likely persist in watersheds affected by the Thomas Fire (e.g., Carpinteria Creek and the Ventura River) for years to come, 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 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.

Operational Findings

The side-by-side operation of DIDSON and ARIS in the Ventura River site revealed some key differences in performance under dynamic winter conditions. The DIDSON was more consistent in providing clear images during times of increased turbidity, while the ARIS' maximum viewing range was considerably decreased during these same periods. When turbidity was not a factor; however, ARIS imagery was noticeably superior to DIDSON. This was expected given that ARIS resolution is twice as high. This increased resolution is the reason for ARIS' limitations regarding range and turbidity because the higher frequency used degrades more rapidly with distance and increased suspended particulate concentration (Maxwell and Grove 2008). ARIS' increased resolution also has a direct effect on file size. ARIS files are typically three times larger than DIDSON files of the same length. This increased file size complicated file storage and added to the amount of time required to process files during analysis. For this reason, as well as the greater consistency in image quality and target detection, DIDSON footage was primarily used throughout the review process for the Ventura River site. ARIS files were reviewed in instances when a large fish was observed and species could not be confidently determined based on DIDSON footage alone. The dual deployment of DIDSON and ARIS cameras had the additional benefit of providing redundancy. In the event one of the cameras experienced technical difficulties, footage from the other camera was still available. This kept gaps in data collection to a minimum.

The use of a second DIDSON in the Ventura River, deployed at a 90-degree angle relative to the adjacent camera, yielded promising results. This configuration allowed for improved views of key morphological features (e.g., fin size and shape, body depth) as well as the fish's position in the water column. The utility of this secondary view was; however, highly dependent on the distance and angle of the fish relative to the camera as it passes by. Fish swimming at oblique angles closer to the camera were easier to discern. The lateral field of view was also greatly decreased for the rotated DIDSON. As a result, fast moving fish were difficult to detect. Despite limitations, the alternate view was useful overall. Having the ability to review footage with better depiction of fine scale physical features was a powerful tool when resolving cases where species identification was ambiguous.

Species Determination

The most considerable challenge posed by sonar monitoring in project systems has been species identification. Difficulties regarding species designation based on DIDSON footage have been well-documented (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) and acoustic shadows (Langkau et al. 2012). At this time, neither option is feasible for southern California steelhead monitoring applications. The current means of differentiating between species 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) this project sought to explore additional means of differentiating between species by further examining observable characteristics such as swimming motion and morphological features. In addition, relationships between stream conditions (i.e., flow), temporal distribution (i.e., time of day observed) and behavioral patterns were explored as suggested by Pipal et al. (2012). Hourly detection rates of Common Carp were negatively associated with stream flow in both years. This suggests flow has a limiting effect on Carp mobility and may offer an additional means of distinguishing *O. mykiss* from *C. carpio* based on stream conditions. Our assessment of diel patterns in Carp movement suggest a tendency towards nocturnal activity. These findings contribute to our understanding of overlap in the diel rhythms of *O. mykiss* and *C. carpio* in the Ventura River.

The large number of *C. carpio* observed in the Ventura River provided abundant opportunities to develop an understanding of Carp swimming behavior, morphological characteristics and behavioral responses to environmental conditions. Unfortunately, DIDSON footage of large southern California *O. mykiss* is scarce. On rare occasions, project staff was able to obtain footage of large *O. mykiss* in non-study watersheds. This imagery has been helpful in providing a limited basis for comparison between the species, but cannot substitute for imagery obtained of both species under actual winter deployment conditions. Species designation will remain a problem until more steelhead imagery is obtained, and more definite metrics for species determination can be evaluated.

According to a recent study on Pacific Lamprey occupancy in coastal drainages of California, our observations of Pacific Lamprey in the Ventura River are the first since 2005 (Stewart and Goodman

2016). Prior to the first observation, Lamprey were not considered as a species that would overlap in size and timing with migrating steelhead in the Ventura. Fortunately, once Pacific Lamprey were recognized as a potentially observed species, subsequent Lamprey observations were readily distinguished due to their distinctive anguilliform swimming motion, body shape and the time of day in which they were observed (i.e., at night) (Keefer et al. 2013, Kirk et al. 2015).

Drought

This project was completed under severe drought conditions, which began in 2011 (Miskus 2018). Mean annual rainfall in project watersheds for the past five years has ranged from 62% to 74% of historical averages (Santa Barbara County Public Works Department 2018, Ventura Watershed Protection District 2018). Consequent reductions in surface flows have decreased opportunities for anadromous *O. mykiss* to reach DIDSON monitoring sites in several ways. Each study watershed experiences seasonal estuary closures due to formation of a sand bar. Until this sand bar is breached, steelhead are unable to enter the system. In 2018, the sand bar at the mouth of the Santa Ynez River remained intact for the duration of the winter season, and precluded DIDSON deployment in Salsipuedes Creek. The prevalence of low flow conditions also contributed to the persistence of low flow barriers. These barriers, noted by concurrent spawning surveys, likely prevented anadromous adults from reaching during low flow (~ < 20 ft^{-3} s^{-1}) conditions in the Ventura River.

Oncorhynchus mykiss Observations

The two *O. mykiss* recorded in Salsipuedes Creek in 2017 were measured below the CDFW listed lower size limit for steelhead (40 cm) at 33 cm and 38 cm respectively. These sizes suggest that these trout derive from a resident life history. However, further research is needed to explore relationships between growth rates and life history strategies in southern California before any meaningful conclusions can be inferred. Our lack of *O. mykiss* $\geq$ 40 cm recordings for sites in Carpinteria Creek and the Ventura River were supported by concurrent redd surveys in both watersheds, during which no steelhead were observed.

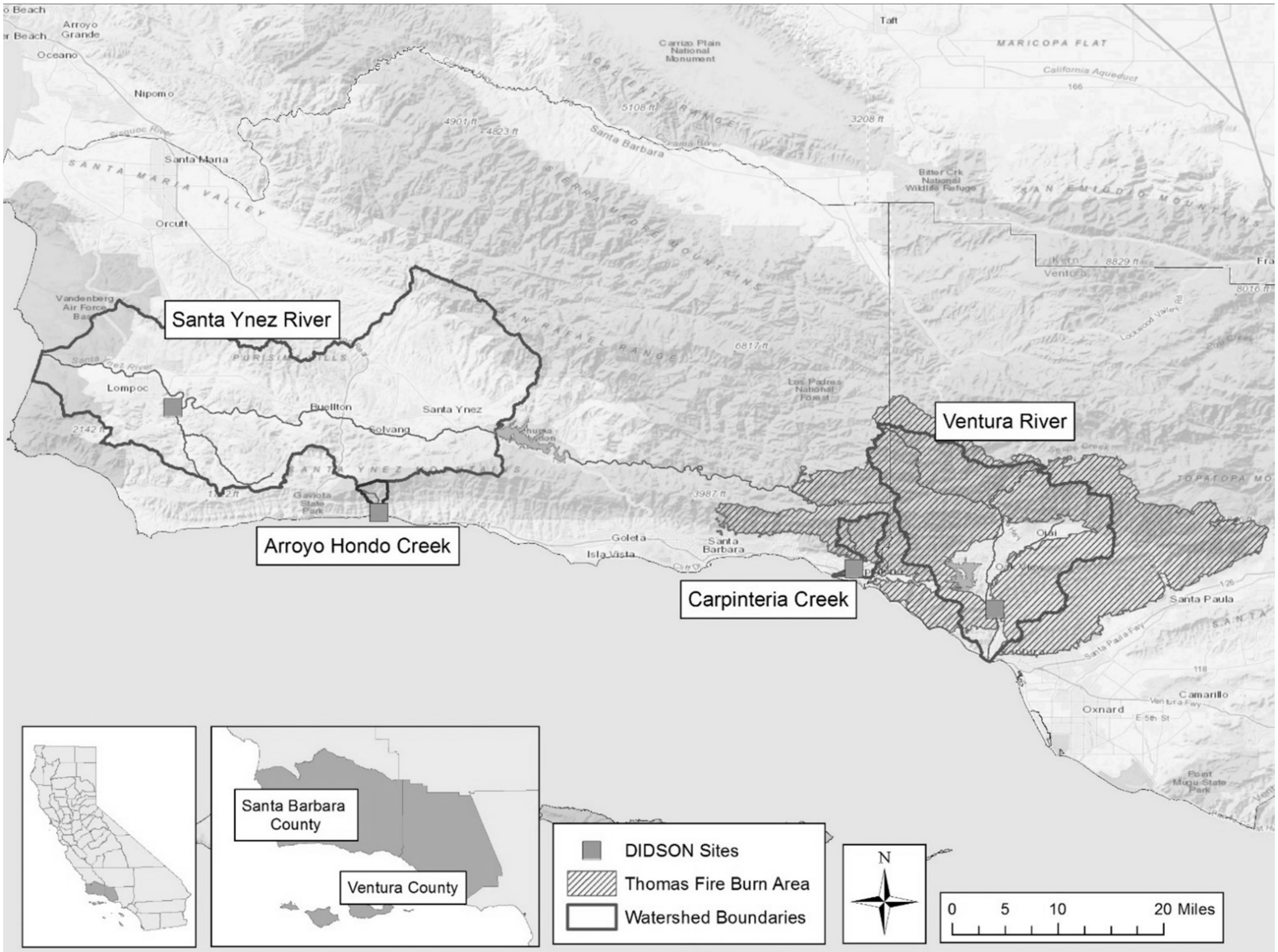

Figure 1. DIDSON monitoring sites located in Santa Barbara and Ventura Counties. In 2017, sonar cameras were deployed at designated sites in Salsipuedes Creek (Santa Ynez River), Carpinteria Creek, and Ventura River. Following the impacts of the Thomas Fire during the 2017-2018 winter season, cameras were deployed in Arroyo Hondo Creek and Ventura River.

Figure 2 Salsipuedes Creek DIDSON deployment track system in 2017 with key features labeled. (A) winch; (B) track; (C) cross-bracing cables; (D) deflection panels; (E) DIDSON/X2/sled assembly.

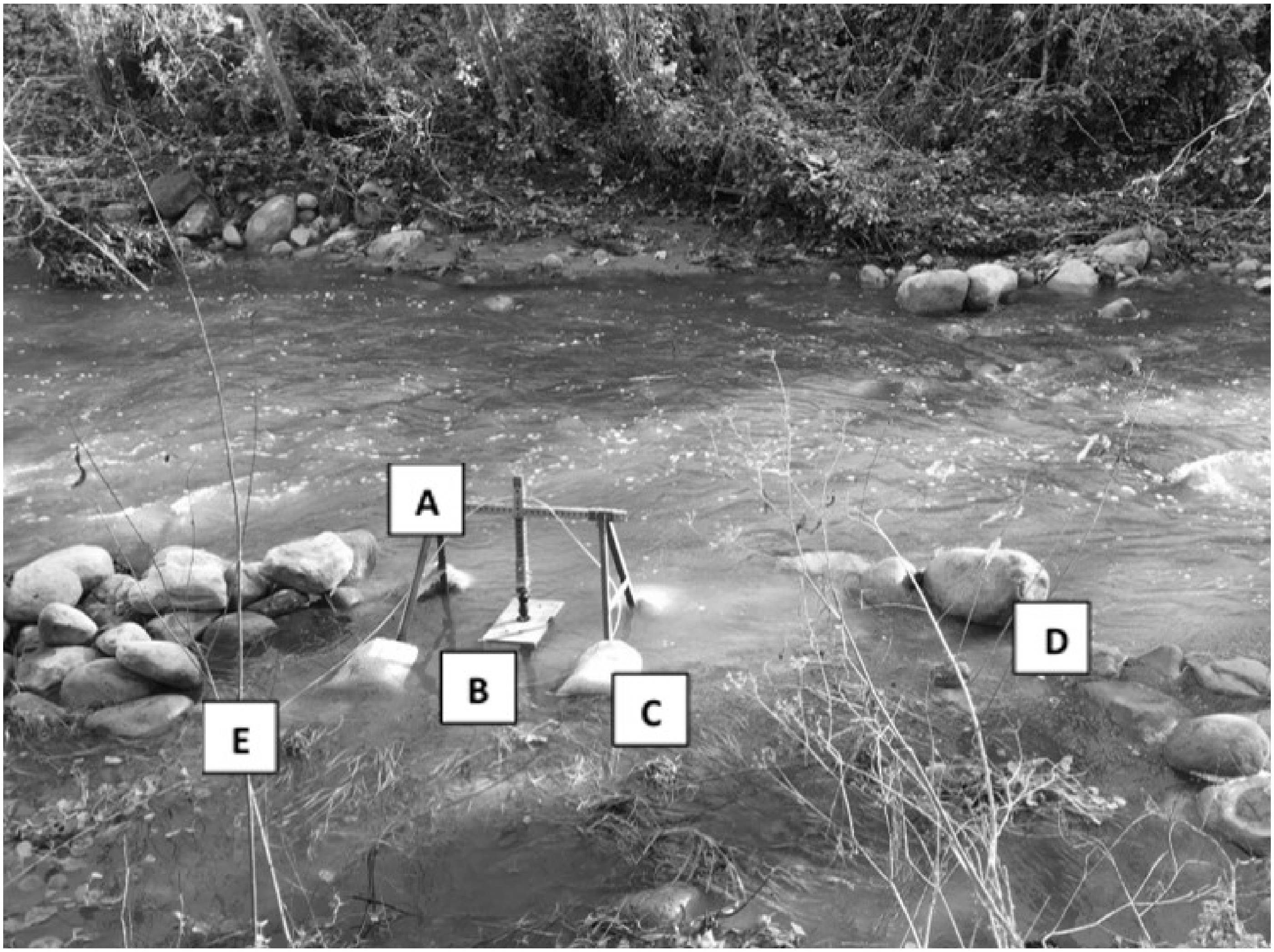

Figure 3. Carpinteria Creek DIDSON deployment infrastructure in 2017 with key features labeled. (A) A-frame; B) DIDSON housed in a debris box and silt box; (C) gravel bags anchoring sled feet; (D) deflection panels; (E) security tether.

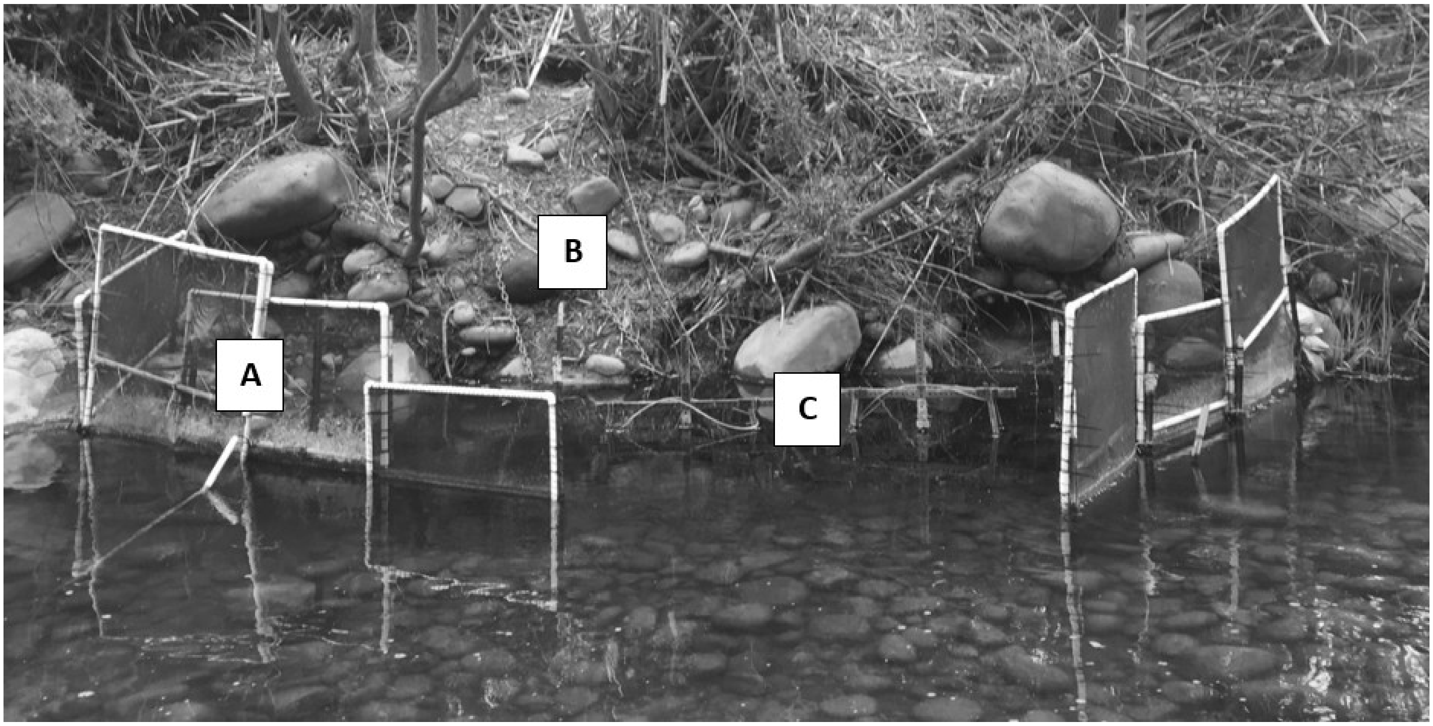

Figure 4. Ventura River monitoring site in 2017 with key features labeled. (A) Deflection panels; (B) security tether; (C) paired deployment of DIDSON and ARIS.

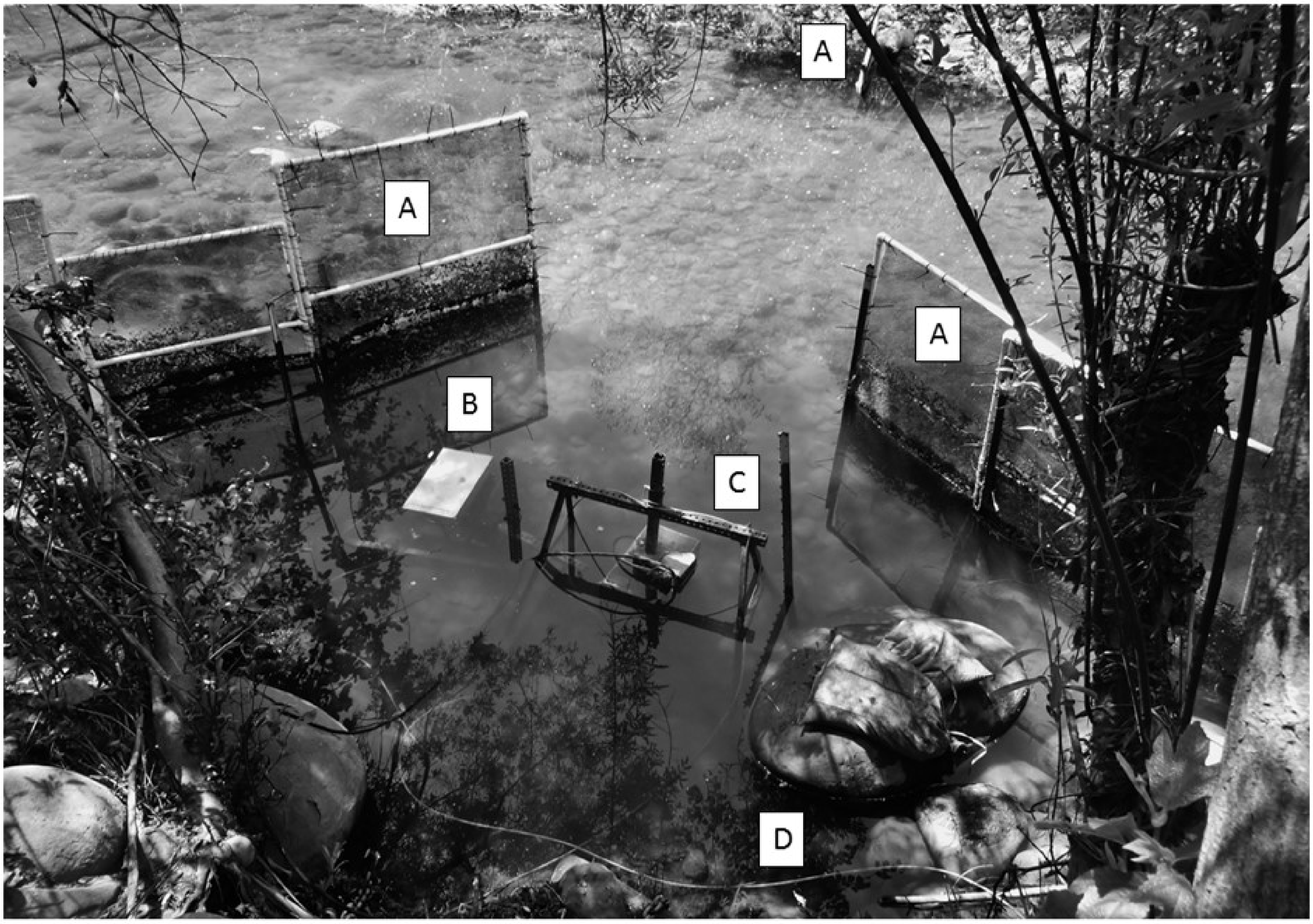

Figure 5. Ventura River monitoring site with two DIDSON cameras deployed in parallel in 2018. Key features are labeled. (A) Deflection panels; (B) DIDSON camera positioned 90 degrees from vertical; (C) DIDSON camera deployed in the standard configuration; (D) security tether.

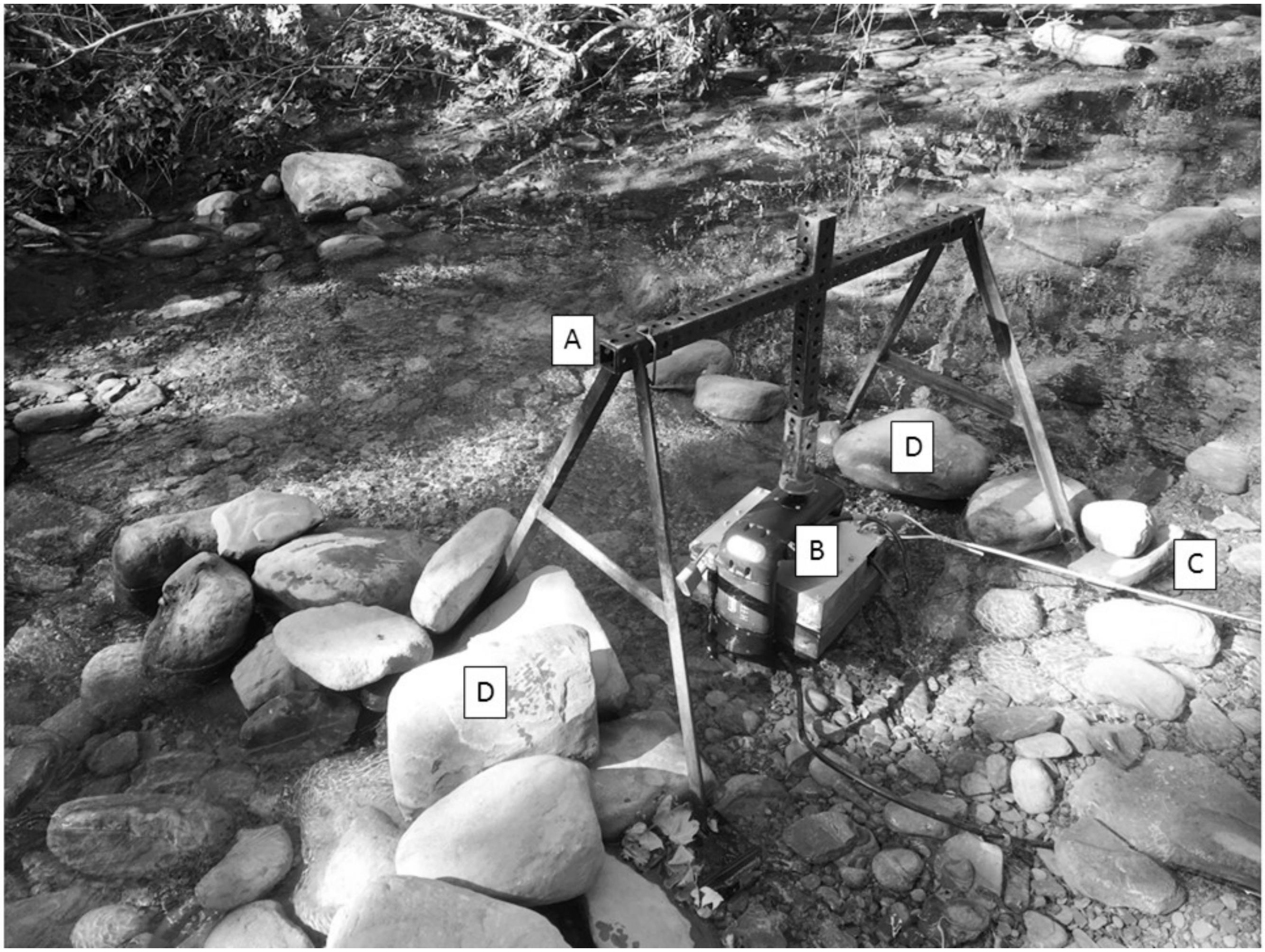

Figure 6. Arroyo Hondo Creek DIDSON deployment in 2018 with key features labeled. (A) A-frame mount; (B) ARIS/AR2 rotator assembly; (C) security tether; (D) cobble berms.

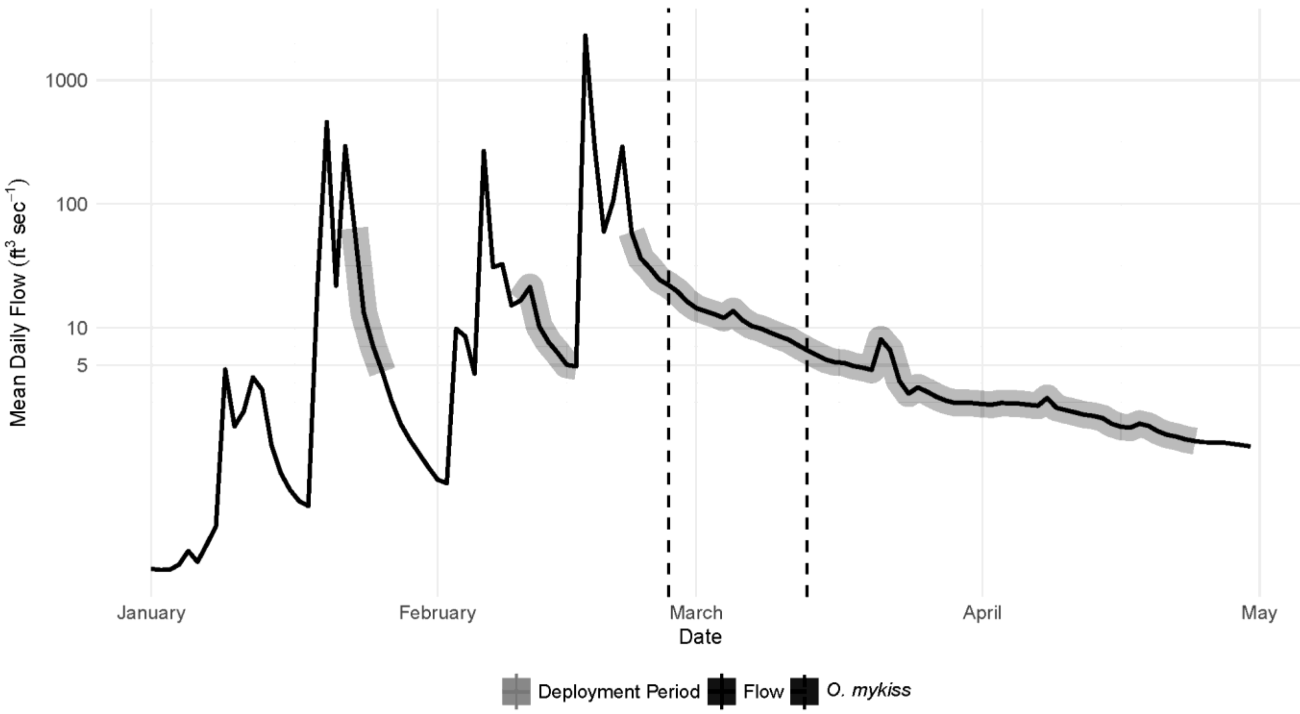

Figure 7. Mean daily stream flow in Salsipuedes Creek plotted against time for 2017 on a $\log_{10}$ scale. Time intervals corresponding to DIDSON deployment events area are shown in grey. Camera deployment was suspended during peak flows to avoid damage to or loss of equipment. *O. mykiss* observations times are indicated by vertical dashed lines.

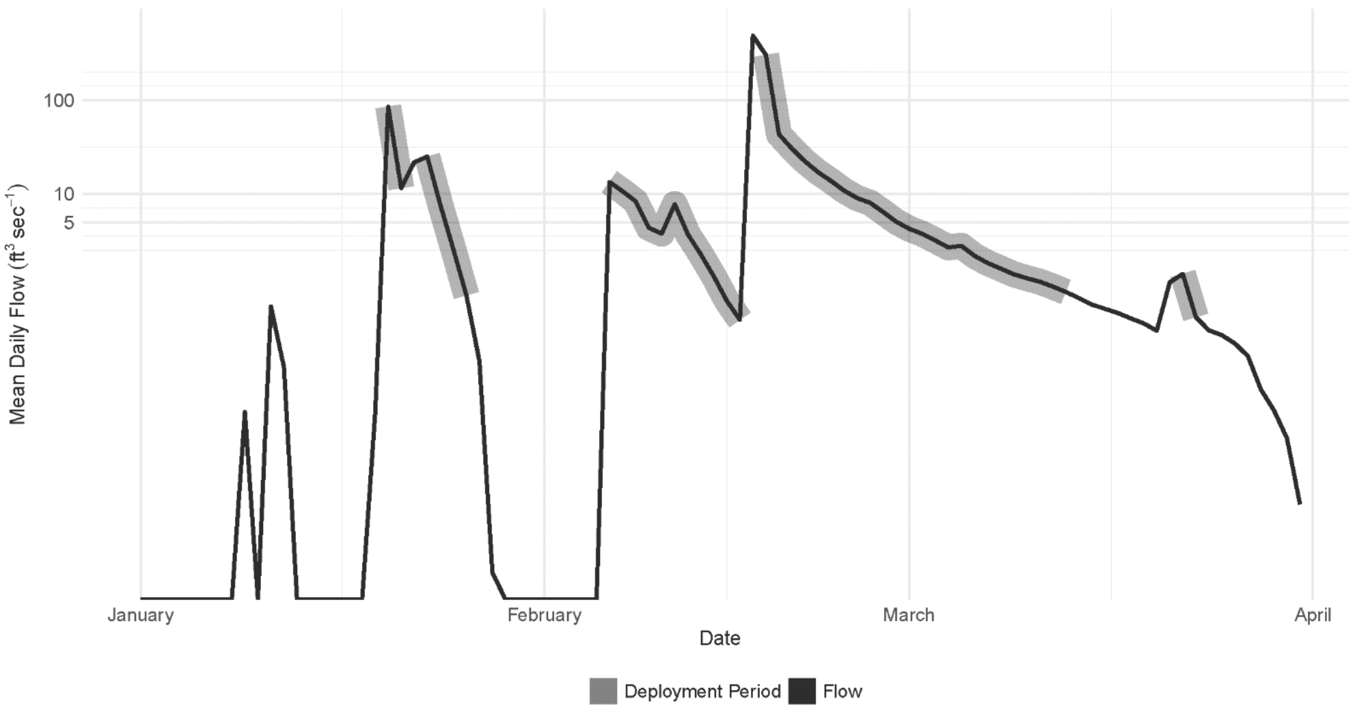

Figure 8. Mean daily stream flow in Carpinteria Creek plotted against time on a $\log_{10}$ scale for 2017. Time intervals corresponding to DIDSON deployment events area are shown in grey. Camera deployment was suspended during peak flows to avoid damage to or loss of equipment.

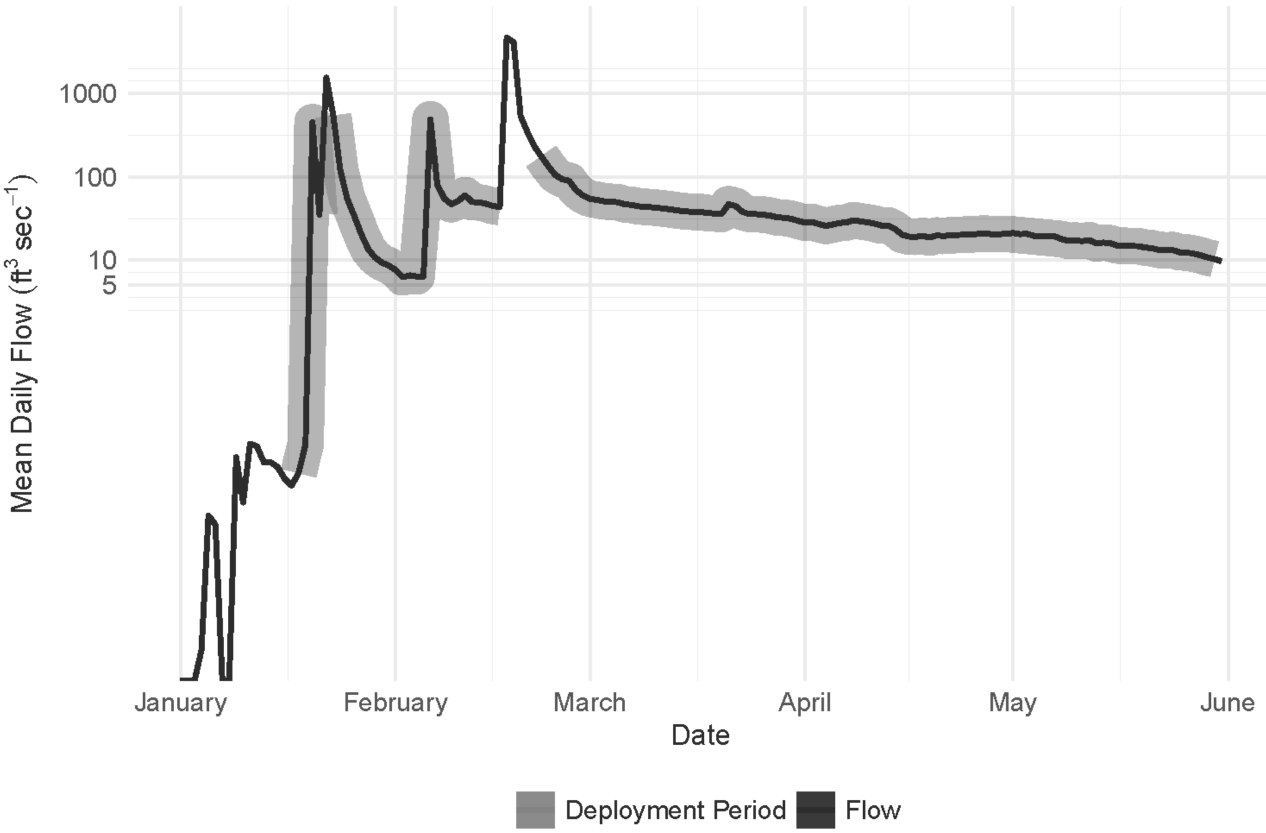

Figure 9. Mean daily stream flow in the Ventura River plotted against time for 2017 on a log_{10} scale. Time intervals corresponding to DIDSON deployment events area are shown in grey. Camera deployment was suspended during peak flows to avoid damage to or loss of equipment.

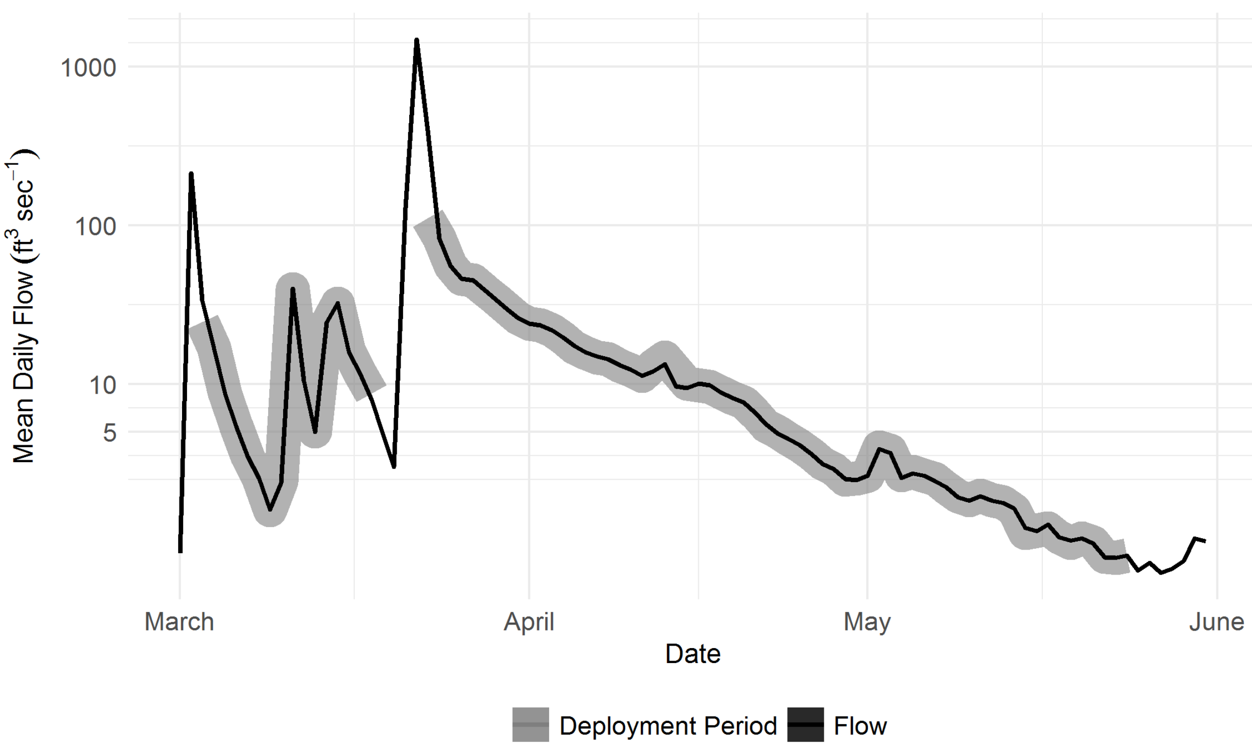

Figure 10. Mean daily flow and sonar deployment in the Ventura River for 2018 on a $\log_{10}$ scale. Periods corresponding to sonar deployments are shown in grey. Camera deployment was suspended during peak flows to avoid damage to or loss of equipment.

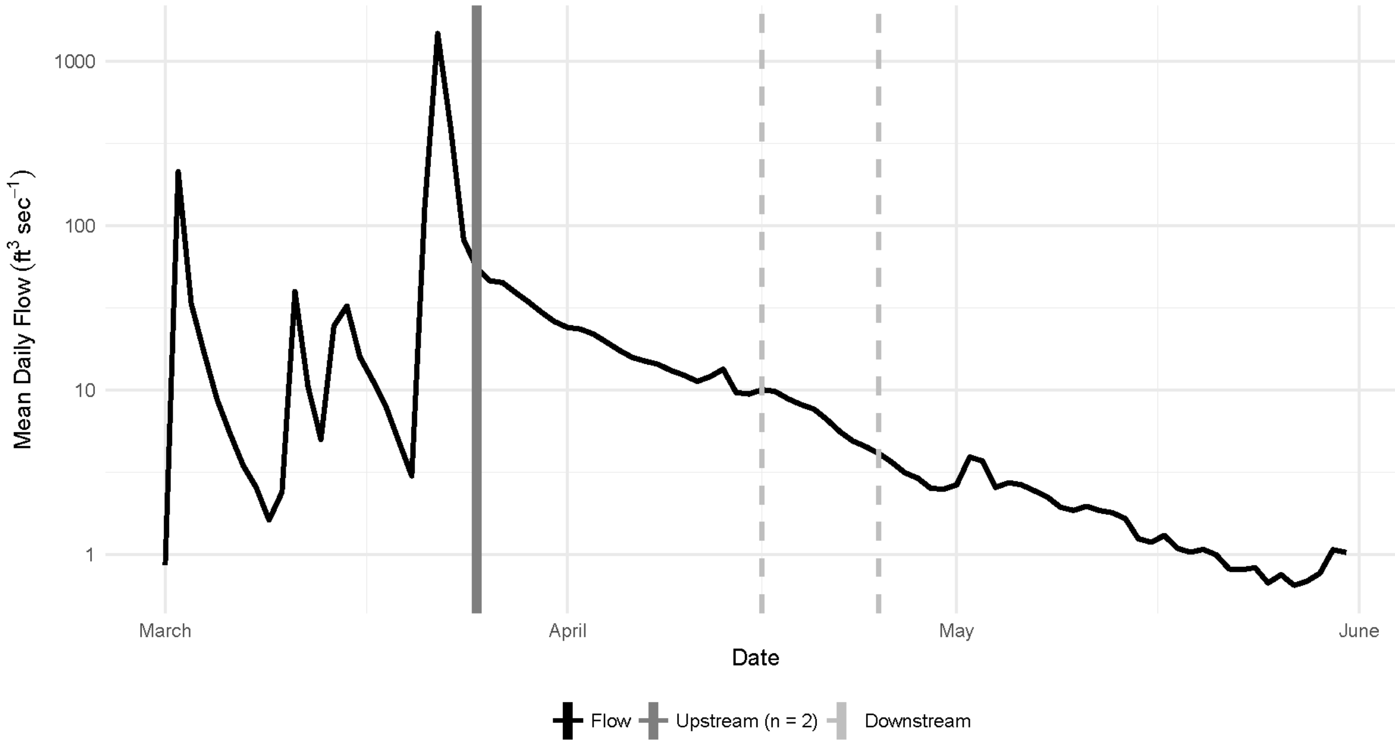

Figure 11. Pacific Lamprey observations recorded in the Ventura River in 2018. Mean daily stream flow values are shown in black on a $\log_{10}$ scale. Vertical lines indicate when Pacific Lamprey were observed.

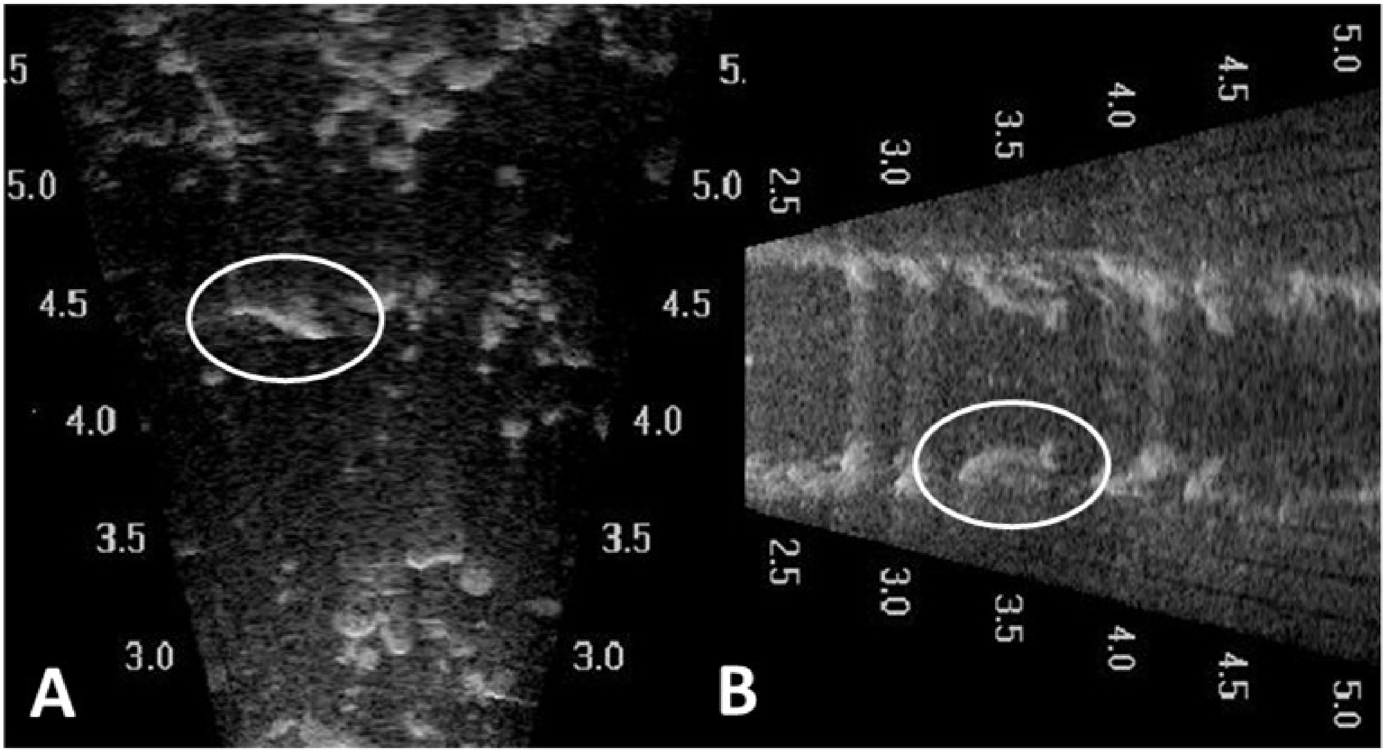

Figure 12. Stills taken from synchronized footage of a Common Carp at the Ventura River site on April 20, 2018 from two DIDSON cameras deployed in parallel. (A) Imagery from a DIDSON in the standard orientation, where the Carp is shown with a top down view. (B) The same carp imaged by a DIDSON rotated 90 degrees. This produces a side view of the carp that better depicts body depth and shape in addition to indicating the fish's position in the water column.

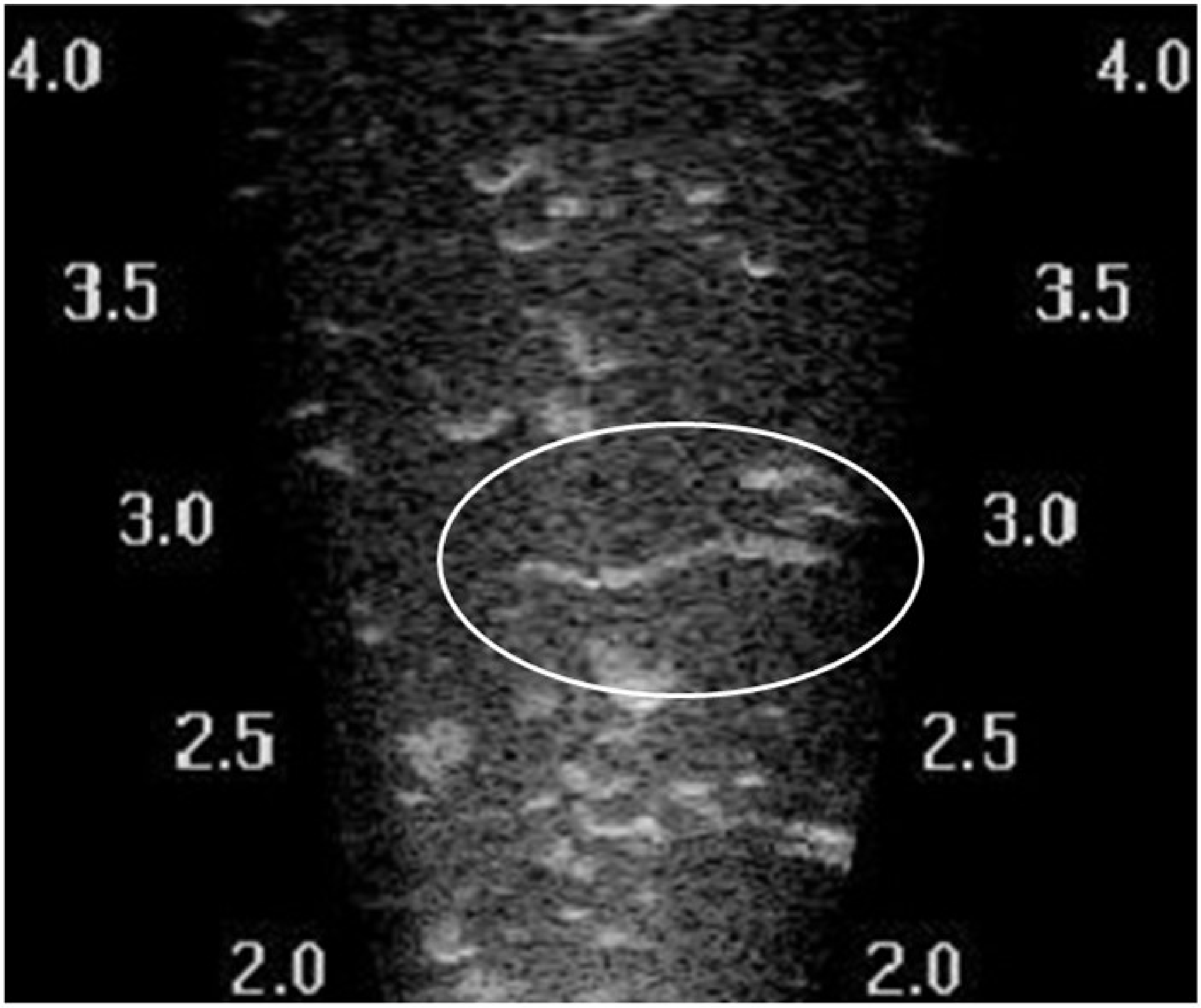

Figure 13. A still taken from DIDSON footage of a Pacific Lamprey recorded at the Ventura River site at 0320 on March 25, 2018. This image illustrates the characteristic s-shaped (i.e., anguilliform) swimming motion.

Table 1. Dates, durations and detection efficiencies for sonar camera deployments in 2017.

Site	*Start*	*End*	*Duration (days)*	*Detection Efficiency*
Salsipuedes Creek	1/23/2017	1/26/2017	3	100%
	2/10/2017	2/16/2017	6	100%
	2/22/2017	4/24/2017	61	95%
Carpinteria Creek	1/20/2017	1/21/2017	1	100%
	1/23/2017	1/26/2017	3	100%
	2/6/2017	2/16/2017	9	100%
	2/18/2017	3/13/2017	23	100%
	3/22/2017	3/23/2017	1	100%
Ventura River	1/18/2017	1/21/2017	3	100%
	1/23/2017	2/16/2017	24	100%
	2/22/2017	5/30/2017	97	99%

Table 2. Dates, durations and detection efficiencies for sonar camera deployments in 2018.

Site	*Start*	*End*	*Duration (days)*	*Detection Efficiency*
Ventura River	2018-03-03	2018-03-18	15	100%
	2018-03-23	2018-05-24	62	98%
Arroyo Hondo Creek	2018-03-25	2018-04-26	32	100%

Table 3. Ventura River Common Carp observations binned by increments of 20 $ft^3 s^{-1}$ for 2017.

Flow Bins ($ft^3 s^{-1}$)	*Percent of Observations*	*Cumulative Percent*	*n*
0-20	32.26	32.26	9846
20-40	44.77	77.03	13667
40-60	20.28	97.31	6191
60-80	0.94	98.25	286
80-100	1.12	99.37	342
> 100	0.63	100	193

Table 4. Ventura River Common Carp observations binned by increments of 20 $ft^3 s^{-1}$ for 2018.

Flow Bins ($ft^3 s^{-1}$)	*Percent of Observations*	*Cumulative Percent*	*n*
0-20	92.72	92.72	4177
20-40	6.75	99.47	304
40-60	0.44	99.91	20
80-100	0.09	100	4

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