2010 UPPER SACRAMENTO RIVER GREEN STURGEON SPAWNING HABITAT AND LARVAL MIGRATION SURVEYS

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Cover Photo: Multiple green sturgeon larvae sampled on July 18, 2010 using a benthic D-net in the Sacramento River, CA. Photo courtesy of USFWS using an Olympus Stylus 8000 digital camera.

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2010 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys

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Abstract.— Five spawning sites of Southern Distinct Population Segment green sturgeon, *Acipenser medirostris,* were confirmed within a 60 river kilometer (RK) reach of the upper Sacramento River, California in 2010. One hundred and five positively identified green sturgeon eggs were sampled by artificial substrate mats with placement guided by 2008 through 2010 acoustic telemetry data. Eggs were sampled for the third consecutive season from the Sacramento River at RK 424.5 and RK 377, for the second season at RK 407.5 and for the first time at RK 426 and RK 366.5. Four of six egg sample sites had substrates surveyed (RK 426, RK 423, and RK 366) or resurveyed (RK 424.5) using underwater videography. Spawning was detected 35 river kilometers upstream and 24.5 river kilometers downstream of the Red Bluff Diversion Dam (RBDD) prior to the June 15 seasonal dam gate closure and 14 river kilometers downstream prior to, and subsequent to the closure. Spawning assumedly occurred directly below RBDD, as evidenced by a single yolk sac larva captured by a rotary screw trap. The temporal distribution pattern suggested by this third year of study indicates spawning of Sacramento River green sturgeon occurs from early April through mid-June. Sample depths for eggs collected from all of the sites combined ranged from 2.4 to 10.9 m ($\bar{x}$ = 6.9 m). Sacramento River flows and temperatures for the *above* RBDD sites ranged from 166 to 459 m^3s^{-1} ($\bar{x}$ = 293 m^3s^{-1}) and 11.1 to 14.4°C ($\bar{x}$ = 12.8°C) during the estimated spawning period. Sacramento River flows and temperatures for the *below* RBDD sites ranged from 268 to 509 m^3s^{-1} ($\bar{x}$ = 349 m^3s^{-1}) and 11.6 to 15.7°C ($\bar{x}$ = 13.8°C) during the estimated spawning period.

Sampling a benthic D-net between April 28 and August 28 resulted in the capture of 122 green sturgeon larvae derived from two sample sites. Sixty-two green sturgeons were sampled between May 6 and August 2 at the RBDD Bypass Outfall (RK 391). Sixty larvae were sampled between May 31 and August 12 at Tehama Bridge (RK 369). Samples were collected with surface velocities ranging from 1.5 to 1.9 ms^{-1} ($\bar{x}$ = 1.7 ms^{-1}) at RBDD Bypass Outfall and 1.0 to 1.4 ms^{-1} ($\bar{x}$ = 1.1 ms^{-1}) at Tehama Bridge. Water depths of collected samples ranged from 1.1 to 1.7 m ($\bar{x}$ = 1.6 m) at RBDD Bypass Outfall and 2.1 to 2.5 m ($\bar{x}$ = 2.4 m) at Tehama Bridge. Sampling success in this third year of study was attributed, in part, to more consistent effort between fewer sites and hydraulic equipment that allowed repeated sampling in high velocity waters. Overall, green sturgeon larval sampling effort has been successful at sampling the initial emigration from upper Sacramento River green sturgeon egg incubation and hatching areas. Additional studies need to be conducted to determine possible juvenile green sturgeon emigration patterns to overwintering areas in the fall.

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Introduction

The Sacramento River in Northern California currently hosts the only known spawning population of Southern Distinct Population Segment (SDPS) green sturgeon, *Acipenser medirostris* (BRT 2005). This genetically distinct population (Israel et al. 2004) was listed as threatened under the Federal Endangered Species Act on April 7, 2006 (NMFS 2006). As a result, a greater level of concern by the U.S. Bureau of Reclamation (USBR) about the potential impacts of the Red Bluff Diversion Dam (RBDD) to green sturgeon prompted the initiation of multiple studies to determine how various life history stages of this population may be affected by current operations of RBDD. From 2008 through 2010, the USBR and the University of California, Davis (UCD) conducted research and monitoring on the adult life history phase of SDPS green sturgeon (R. Corwin, USBR and M. Thomas, UCD, unpublished data). The U.S. Fish and Wildlife Service (USFWS) concentrated on the earliest life history stages of SDPS green sturgeon through egg deposition and larval drift sampling. Heath and Walker (1987) noted the sampling of eggs and larvae as an important method to identify spawning and nursery areas. Knowledge of these areas has been deemed critical to understand the overall abundance of fish populations (Hjort 1914; May 1974; Hempel 1979). Detailed information on these critical areas for SDPS green sturgeon has been extremely limited.

Four spatially discrete SDPS green sturgeon spawning areas were confirmed in the Sacramento River, CA through egg sampling by the USFWS in 2008 and 2009 (Poytress et al. 2009, 2010). Limited larval drift characteristics were also documented. All data collected as part of the multi-entity collaborative efforts from 2008 through 2010 was used to guide the timing, specific locations, and methods used to conduct the 2010 green sturgeon egg and larval surveys.

Objectives

The objectives of this third-year study were to: (1) determine the temporal and spatial distribution patterns of spawning green sturgeon (via egg deposition) above, at, and below RBDD, (2) monitor 2008 and 2009 confirmed spawning sites for repeated spawning site use, (3) monitor the environmental conditions of the sites where eggs were found by describing spawning habitat in terms of water temperature, depth, river discharge, and substrate type, (4) determine temporal and spatial distribution patterns of emerging green sturgeon larvae in proximity to RBDD, (5) determine if distinct nocturnal patterns of migration occurred in post exogenous feeding larvae, and (6) to determine the timing, spatial distribution, and habitat use of green sturgeon larvae emigrating out of confirmed spawning areas.

This annual report addresses, in detail, egg and larval sampling of green sturgeon for the period March 17 through August 28, 2010. This report includes data and information on green sturgeon spawning areas, larval drift characteristics, and qualitative spawning substrate surveys from multiple upper Sacramento River sites centered on the RBDD. This report is being submitted to the USBR to comply with contractual reporting requirements for funding administered through the Fish and Wildlife Coordination Act.

Study Area

The Sacramento River originates in Northern California near Mt. Shasta from the springs of Mt. Eddy (Hallock et al. 1961). It flows south through 600 kilometers of the state and drains numerous slopes of the Coast, Klamath, Cascade, and Sierra Nevada mountain ranges eventually reaching the Pacific Ocean at the San Francisco Bay (Figure 1). Shasta Dam and its associated downstream flow regulating structure, Keswick Dam, have formed a complete barrier to upstream anadromous fish passage since 1943 (Moffett 1949). The 94 river kilometer (RK) reach between Keswick Dam (RK 485) and RBDD (RK 391) supports areas of intact riparian vegetation and largely remains unobstructed. Below RBDD the river encounters greater anthropogenic influence until it drains into the Sacramento-San Joaquin Estuary.

Sampling was concentrated within a 60 river kilometer reach of the Sacramento River from the mouth of Ink's Creek (RK 426) to an area below Tehama Bridge (Red Barn site; RK 366.5) with RBDD half way in between (Figure 1). The 2010 study area contained four confirmed spawning micro-habitats (Brown 2007; Poytress et al. 2009, 2010) and was expanded to sample two likely spawning micro-habitats associated with the presence of adult green sturgeon based on 2008 through 2010 acoustic telemetry data (R. Corwin, USBR and M. Thomas, UCD, unpublished data). The primary focus of the multi-year study is to assess potential impacts of RBDD operations on green sturgeon spawners and drifting larvae. The study area in 2010, as described, provided six logistically feasible egg sampling locations both upstream and downstream of RBDD and two larval sampling locations below RBDD.

Methods

***Egg sampling surveys*.—** Sampling for green sturgeon eggs was performed by deploying artificial substrate samplers (i.e., egg mats) in close proximity to presumed adult spawning areas based on visual observations, side scan sonar, and acoustic telemetry data (R. Corwin, USBR and M. Thomas, UCD, unpublished data). Egg mats were constructed using two 89 x 61 cm rectangular sections of furnace filter material secured back to back within a welded steel framework (McCabe and Beckman 1990; Schaffter 1997). The orientation of the furnace filter material allowed either side of the egg mat to collect eggs. Egg mats were held in position by a three-fluke cement-filled poly-vinyl chloride (PVC) anchor attached to the upstream end of the egg mat using 9.5 mm diameter braided polypropylene rope. A labeled float was attached to the downstream end of each egg mat using 9.5 mm diameter braided polypropylene rope. Float line length and number of floats varied between egg mats depending on water depth and velocity.

Multiple egg mats were placed in five locations on the Sacramento River commonly known as the mouth of Ink's Creek (RK 426), Massacre Flats (RK 424.5), Turkey Beach (RK 407.5), below the mouth of Antelope Creek (RK 377), and the Red Barn (RK 366.5;

Figure 1). The exact number of egg mats deployed at each site depended upon the physical area of each site and the need to maintain a useable river channel for public river transit or fishing. Mats were predominantly deployed in the within pool microhabitats (areas flanking deepest portions of pools) based on the results of the 2008 and 2009 studies (Poytress et al. 2009, 2010).

Two sets of paired egg mats were placed in the confirmed spawning area (Brown 2007; Poytress et al. 2009, 2010) directly below RBDD (RK 391) following the annual, seasonal gate lowering which occurred on June 15, 2010. Egg mats were deployed downstream of partially opened dam gates (hydraulically active areas) generally flanking locations of observed sturgeon aggregations and activity.

Environmental and sample effort data was collected during both the setting and retrieval of the egg mat samplers. Environmental data consisted of: GPS coordinates recorded at the water surface directly above each egg mat, river flow, water temperature, turbidity, egg mat depth, weather condition, and moon phase. Hourly water temperature was monitored at or near each site using a Stowaway® Tidbit temperature logger maintained by USBR or USFWS personnel. Sacramento River hourly flow data for the three sites above RBDD were obtained from the California Data Exchange Center's Bend Bridge gauging station (http://cdec.water.ca.gov/cgi-progs/queryF?BND). Flows below RBDD were estimated by using Bend Bridge data and subtracting daily diversions at RBDD (when applicable). Sample effort data consisted of the date and time individual egg mats were set and retrieved. When identifiable, it was noted whether egg mats were sampling top or bottom side up.

Egg mat sampling consisted of visual inspection, generally twice a week, throughout the sample period. Paired egg mats were retrieved from the river after initial deployment, placed on the deck of a boat in a custom made egg mat carrier, and initially inspected on both sides by at least two field crew members. After initial inspection, egg mats were rinsed with water to remove debris and sediment and then re-inspected. Rinse water and debris were filtered by a removable 3.2 mm mesh net placed within the egg mat carrier below each egg mat to capture any dislodged eggs. After a second egg mat inspection and inspection of the mesh nets, egg mats were redeployed.

Egg samples were counted and identified to species for each egg mat in the field. Eggs were measured, both maximum length and width, in the field using digital calipers (±0.01 mm). All suspected green sturgeon and unidentified eggs were placed into vials of 95% ethyl alcohol (EtOH) for laboratory identification, species confirmation, and further analysis. Eggs were pooled, by species, into the same vial only when found on the same side of one egg mat. Suspected green sturgeon eggs were sent to UCD for positive species confirmation, photography, measurement of egg diameter, and determination of developmental stage (Dettlaff et al. 1993). Laboratory analysis of EtOH fixed egg size, both maximum length and width, was measured (± 0.001 mm) using an Olympus dissecting microscope with a camera lucida, and a Nikon Microplan II digital image analyzing tablet.

Spawn date was estimated based upon egg collection date and developmental stage and was back-calculated using average daily water temperature (Wang et al. 1985, 1987; Deng et al. 2002) from the nearest Sacramento River gauging station or temperature logger. All confirmed and potential green sturgeon eggs were transferred to Dr. Josh Israel of UCD/USBR for genetic confirmation (Israel et al. 2004). Non-green sturgeon fish eggs were field identified using a draft egg key provided by Rene Reyes and Dr. Johnson Wang of the U.S. Bureau of Reclamation's Tracy Fish Salvage Facility. Non-fish eggs (e.g., amphibian), were noted and returned to the water or saved for laboratory examination.

Spawning substrate surveys.— Qualitative substrate identification and composition surveys of green sturgeon deep water spawning habitat were performed using underwater videography. This technique has been performed in large, deep mainstem rivers focusing on deep water spawning habitat of fall Chinook salmon (*Oncorhynchus tshawytscha*), but also for lake trout (*Salvelinus namaycush*), as well as bottom dwelling burbot (*Lota lota*; Groves and Chandler 1999). Spawning substrate surveys were performed using a black and white Delta Vision Industrial underwater video camera (UVC) made by Ocean Systems Incorporated. The camera housing was attached to a protective carrier and suspended from the bow of a boat using two 11 kg sounding weights (Groves and Garcia 1998) for added stability in fast moving water environments. A 12 volt ATV winch was used to raise and lower the protective carrier in the water column during deployment. Video images were recorded on a 4 channel 12 volt mobile DVR with GPS and displayed in real-time on an 18 cm LCD monitor.

Surveys were composed of three longitudinal transects along river right, mid-channel, and on river left at egg sampling sites. Each transect surveyed with the UVC typically proceeded from the furthest point downstream to the upstream end of suspected sturgeon spawning areas, based on the presence of acoustically tagged adults or sampling of green sturgeon eggs. The UVC (facing upstream) was lowered in the water column, near the pool tail crest until substrate was clearly visible on the LCD monitor. Surveys progressed slowly upstream (1- 2 km/hr) through the pool microhabitats with the UVC raised and lowered to keep within 30 cm of the river bottom. GPS waypoints were taken at the beginning and end of each transect. Individual transects were further broken down into segments using land based markers in an attempt to produce a grid or matrix of GPS waypoints and substrate features. At the end of each pass, the UVC was raised to the water surface or secured onboard within the deployment apparatus.

Generally, each holding pool was surveyed for observation data including GPS location, time, substrate type, river depth, and notable underwater and above water physical features recorded for later reference. Recorded video was later played using the DVR's video software to combine field notes, GPS coordinates, and video footage in a word processing document. Snapshots, video segments, and GPS were combined to designate specific microhabitats within each survey site. Substrate size class was visually estimated using substrate descriptors listed in Dunne and Leopold (1978). Substrates were classified as sand (<2.0 mm), gravel (2.0 to 64.0 mm), cobble (64.0 to 256.0 mm), and boulder (>256.0 mm).

Larval migration surveys.— Larval drift sampling was scheduled to occur two weeks following the first egg sample collection, based on spawning (Brown 2007; Poytress et al. 2010) and juvenile outmigration timing (Gaines and Martin 2002), through August. Successful egg capture during the concurrent USFWS egg mat sampling surveys refined the exact start and end dates. Based on previous studies on the Sacramento River (Brown 2007; Poytress et al. 2009, 2010) and laboratory studies (Van Eenennaam et al. 2001; Kynard et al. 2005) indicating nighttime migration activity, larval sampling was planned to occur primarily between the hours of 20:00 and 02:00.

A benthic D-net was used throughout the season, similar to nets previously used for larval sturgeon sampling in the Sacramento River (Kohlhorst 1976; Brown 2007). The net was constructed of 1.6 mm polyester mesh fashioned into a 2.4 m long tapered cone and attached to a steel frame with a circumference of 2.8 m including a flat base of 80 cm. A 2,200 mL Wildco Dolphin bucket was attached to the cod end allowing for easy access to collected samples. Steel bar stock was added to the base of the net frame to properly orient the net in the current and to sink it to the river bottom during sampling. A total weight of 27 kg was determined to be sufficient for proper net orientation during sampling. The net was attached via a 4.8 mm diameter wire rope bridle to 4.8 mm Amsteel Blue rope and positioned using a hydraulic winch. The net was allowed to drift downriver behind the boat until it contacted the river bottom.

Larval drift sampling was scheduled for five nights per week alternating between two sample sites: RBDD Bypass Outfall (RK 391) and Tehama Bridge (RK 369; Figure 1). Sites were selected based on proximity to confirmed spawning locations, ease of access at night, and the presence of adequate tie-off structures (e.g., bridge supports) in the thalweg. The RBDD Bypass Outfall was selected as a sample site based on previous larvae catch (Poytress et al. 2009, 2010) and historic catch in the RBDD rotary screw traps (Gaines and Martin 2002). Tehama Bridge was selected as the next nearest downstream sampling location 8 river kilometers below confirmed spawning grounds (Poytress et al. 2009, 2010).

Sampling effort was generally designed to consist of 300 minutes of wetted net time per night between the hours of 20:00 to 01:00 and continued for one hour past the last collection of green sturgeon larva. Four bridge supports at Tehama Bridge allowed for multiple sampling locations (i.e., tie-offs), however, bridge support two was used as it was located in the thalweg. At the RBDD Bypass Outfall, one river center tie-off existed for all sampling efforts. During standardized sampling, the net was generally set to sample for 10, 20, 30, or 60 minute sets depending on debris accumulation, fish occurrence, and mortality.

Effort and environmental data collected for each sample site included: set and retrieve times and dates, tie-off distance, net set distance, sample depth, turbidity, and river velocity. D-net sample depth was measured by mounting an Onset Corporation ® Depth Logger to the frame of the D-net. The river velocity was measured just below the surface adjacent to the sampling vessel using a General Oceanic® Model 2030 flowmeter. Set time was recorded as the time the net became properly oriented in the river during deployment and retrieve time was recorded when the net broke the surface during retrieval.

Collected samples were field sorted with the amount and type of debris recorded. All fish sampled were identified, measured, enumerated, and recorded. Eggs were identified to species and enumerated or were retained in 95% EtOH for laboratory examination and species identification. Green sturgeon larvae incidental mortalities (morts) and eggs were retained in 95% EtOH for genetic identification (Israel et al. 2004) and developmental stage assessment (Dettlaff et al. 1993). Live green sturgeon larvae in good condition were returned to the river or subsampled for transfer to the USBR river lab for use in an additional UCD research effort (NMFS 2009). Non-sturgeon eggs were identified using a draft egg identification key provided by Rene Reyes and Dr. Johnson Wang of the U.S. Bureau of Reclamation's Tracy Fish Salvage Facility. Larval fish samples were visually identified or confirmed to the genus level primarily in the field and in some cases in the lab.

***Experimental larval sampling surveys*.—** Exploratory larval sampling was conducted *within* spawning locations on a limited basis, similar to 2009 (Poytress et al. 2010). These efforts focused on sampling from dusk until dawn in areas where eggs were sampled within the season to detect early dispersion from the spawning grounds and to determine nocturnal distribution patterns. Gear and data collection efforts were the same as the five night per week standard larval sampling regime.

Results

***Egg sampling surveys*.—** Egg mat sampling occurred between March 17 and July 25, 2010. RBDD mats were deployed on June 22, 2010, following the lowering of the dam gates on June 15, 2010, and sampled until July 25, 2010. Egg mats sampled a total of 1,835.7 wetted mat days (wmd; one mat set 24 hours; Table 1). Sampling effort between the six sites ranged from 128.1 to 427.8 wmd ($\bar{x}$ = 305.9 wmd; Table 1). On five occasions during April all sites' mats were retrieved due to a storm/flow event and redeployed two to seven days later. Three mats were lost over the course of the sampling season when they could not be retrieved after being buried by fine sediments.

Between April 11 and June 16, 2010, 105 eggs were sampled by egg mats and positively identified as green sturgeon eggs (Table 2). Positively identified egg samples were collected at RK 426 ($N = 1$), RK 424.5 ($N = 93$), RK 407.5 ($N = 1$), RK 377 ($N = 9$), and RK 366.5 ($N = 1$). Egg samples were collected on 14 different sample days (Figure 2). Daily positive egg sample totals per site ranged from 1 to 45 ($\bar{x}$ = 7.5). On six occasions eggs were sampled from two different mats within the same site. On one occasion (May 7, 2010) eggs were sampled from four different mats within the same site. Green sturgeon eggs were found adhered to the top ($N = 60$) and bottom ($N = 45$) of the egg mats. On three occasions eggs were found on both sides of the same egg mat.

Catch per unit effort (sturgeon eggs/wmd) ranged from 0.000 at the RBDD site to 0.298 at the Massacre Flats site ($\bar{x}$ = 0.055). Catch per unit effort for all sites combined totaled 0.057 green sturgeon eggs/wmd (Table 1).

Sixty-nine of 105 eggs (66%) were assessed for developmental stage and described using Detlaff et al. (1993). Four eggs (4%) were determined to have *not* been fertilized.

Three eggs (3%) were covered with fungus (dead) and 29 eggs (28%) fertilization or viability could not be determined. Embryonic developmental assessment indicated eggs were between stage 2 (grey crescent) and stage 32-33 (pre-hatch larva). Eggs were collected, on average, at stage 11 and 12 (late-cleavage and early to late blastula; Table 2). Based on capture location, date of capture, water temperature, differing stages of development, and the assumption that a female requires 12 to 20 hours to release all of her eggs, samples were likely collected from 15-17 different females who spawned between April 11 and June 16, 2010 (Table 2).

Egg diameter (width and length) was measured in the field prior to fixation on 90% of the egg samples. Seventy-five percent of the samples were also measured in the laboratory (post fixation). By direct comparison, field egg diameter measurements (N = 76) were slightly larger for both width and length measurements. Field width and length measurements ranged from 3.23 to 5.43 mm ($\bar{x}$ = 4.00 mm) and 3.49 to 5.57 mm ($\bar{x}$ = 4.35 mm), respectively. Laboratory width and length egg diameter measurements ranged from 3.48 to 4.61 mm ($\bar{x}$ = 3.88 mm) and 3.42 to 4.91 mm ($\bar{x}$ = 4.12 mm), respectively.

Egg mats sampled in water depths ranging from 0.8 to 14.5 m ($\bar{x}$ = 5.5 m; Table 3). The results of a paired t-test comparison of average set and retrieve depths for all sites combined indicated no significant difference (t = 0.65, df= 5, P = 0.26). Sample depths for green sturgeon eggs collected from all of the sites combined ranged from 2.4 to 10.9 m ($\bar{x}$ = 6.9 m; Figure 3).

Sacramento River flows during the sample period above RBDD ranged from 154 to 509 m^3s^{-1} ($\bar{x}$ = 309 m^3s^{-1}) at RK 426, RK 424.5, and RK 407.5 (Figure 4). Sacramento River flows during the sample period below RBDD ranged from 154 to 509 m^3s^{-1} ($\bar{x}$ = 312 m^3s^{-1}) at RK 377 and RK 366.5 (Figure 5). Flows generally increased over the sample period due to Shasta/Keswick Dam releases during the primary agricultural irrigation season. During the sample period five spring storm events in April and June resulted in spikes on the hydrograph and corresponded to the peak flow values noted at all sample sites.

Sacramento River flows ranged from 166 to 459 m^3s^{-1} ($\bar{x}$ = 293 m^3s^{-1}) at Bend Bridge gauging station during the estimated spawning period at RK 426, RK 424.5, and RK 407.5 (Figure 4). Flows ranged from 268 to 509 m^3s^{-1} ($\bar{x}$ = 349 m^3s^{-1}) during the estimated spawning period at RK 377 and RK 366.5 (Figure 5).

Instantaneous turbidity grab sample values from the above RBDD sites ranged from 1.1 to 187.0 nephalometric turbidity units (NTU) throughout the sample period ($\bar{x}$ = 4.8 NTU). During the estimated spawning period, turbidity ranged from 1.8 to 187.0 NTU ($\bar{x}$ = 8.5 NTU). Instantaneous turbidity grab sample values from the RBDD and below sites ranged from 1.1 to 69.6 NTU ($\bar{x}$ = 4.5 NTU) throughout the sample period. During the estimated spawning period at RK 377 and RK 366.5, turbidity ranged from 2.0 to 11.5 NTU ($\bar{x}$ = 4.0 NTU).

Mean daily water temperatures ranged from 9.3 to 14.6°C ($\bar{x}$ = 12.7°C) at RK 426, RK 424.5, and RK 407.5 (Figure 4). Mean daily water temperatures ranged from 9.7 to 15.7°C ($\bar{x}$ = 13.8°C) at RK 377 and RK 366.5 (Figure 5). During the estimated spawning period, water temperatures ranged from 11.1 to 14.4°C ($\bar{x}$ = 12.8°C) at RK 426, RK 424.5, and RK 407.5 and between 11.6 to 15.7°C ($\bar{x}$ = 13.8°C) at RK 377 and RK 366.5.

***Spawning substrate surveys*.—** Multiple pass UVC surveys were performed within green sturgeon egg mat sampling sites at RK 426 and RK 424.5 on August 24, 2010. Sacramento River discharge was 269 m^3s^{-1}. Both sites' pools result from the river current scouring a large hole as water deflects off naturally occurring bedrock on the river left bank. The multiple pass UVC survey at RK 426 showed the pool tail was comprised of scattered cobble embedded with gravel and sand (Figure 6). As each pass proceeded upstream, the substrate composition changed likely due to the pool's hydraulic influences. Near the midpoint of the river right pass, the substrate consisted of increasing proportions of sand until becoming the only component in the backwater eddy behind a point bar at the end of the pass. Within the deepest portion of the pool (13 m), the substrate increased in size to cobble and scattered boulders and was devoid of sand. Large bedrock boulders were located at the upstream end of the river left pass where the surface water velocity appeared greatest near the head of the pool.

The UVC survey at RK 424.5 generally revealed a smaller substrate composition, when compared to RK 426 (Figure 7). A large backwater eddy held deposited sand and other woody debris along the river right bank. Underlying hardpan that had not been noted in a prior survey of this site (Poytress et al. 2009) was observed at the upstream end of the pass. Pockets of sand and small gravel flanked the deepest portion of the pool (17 m). The highest water velocity areas (on river left) contained primarily a clean, homogenous gravel-cobble mixture, except at the head of the pool. Patches of underlying hardpan were exposed in this area.

The Salmon Hole (RK 423), a 2009 egg mat sampling site (Poytress et al. 2010), is known to hold adult green sturgeon during the spawning season (R.Corwin, USBR, pers. comm.; M. Thomas, UCD, pers. comm.). However, egg mat sampling in 2009 did not confirm it as a spawning location. A UVC survey was completed on July 28, 2010 with Sacramento River flows at 361 m^3s^{-1} as staff were not available in 2009 to conduct a survey. Pool topography was relatively even at this site. Water depth gradually increased from 3 to 5.5 meters before rapidly increasing to 13 meters in the deepest portion of the pool. Low velocity areas located downstream of the midpoint of the river right and river center pass contained an embedded gravel-cobble mix (Figure 8). Within the upstream portions of these segments, pockets of mobile sand could be observed shifting around in the current. The river left segment contained a homogenous gravel substrate that was devoid of sand.

The final 2010 survey was conducted at RK 366.5 on August 27, 2010 with Sacramento River flows at 241 m^3s^{-1}. Substrates varied widely throughout this site (Figure 9). The river right substrate was dominated by sand deposits overtop gravel. Scattered large woody debris was also present. The mid-channel environment was primarily composed of a gravel-cobble mix that had exposed hardpan in the higher water velocity areas. Substrate in the lower velocity river left area contained the most variable substrates from gravel to boulders. However, the substrates were covered in a layer of algae.

Larval migration surveys.— Larval drift sampling occurred from April 28 to August 28, 2010. Wetted net time totaled 440 hours (26,384 minutes) during weekly standard sampling efforts Sunday through Thursday nights (Table 4). RBDD Bypass Outfall site was sampled every other night generally from 20:00 to 01:00. Sampling at Tehama Bridge (RK 369) occurred on the alternate nights during the same hours. Net set times ranged from 13 minutes to 65 minutes ($\bar{x}$ = 32.1 minutes).

As noted in the egg sampling results section of this report, five storm/flow events occurred during the sampling season. Sacramento River conditions during the RBDD gates lowered period were primarily the result of water releases from Shasta/Keswick Dam (Figures 4, 5). Turbidity values derived from surface grab samples at RBDD Bypass Outfall ranged from 1.3 to 31.7 NTU ($\bar{x}$ = 3.3 NTU) and 1.1 to 16.6 NTU ($\bar{x}$ = 3.1 NTU) for the Tehama Bridge site. Debris loads from collected samples were generally light to moderate, typically consisting of leaves and aquatic vegetation.

D-net sampled depth data was recorded using an Onset depth logger attached to the net and downloaded each night. Data derived from the logger allowed us to determine which net sets sampled properly as indicated by the variability of the measurements during each deployment. On May 30, 2010, the primary net was lost in the river with the depth logger. An alternate net was used for the remainder of the season, yet a replacement depth logger was not activated until July 6, 2010. During this period the depth off the starboard side of the boat was measured as a proxy for net depth. Nine larvae were sampled during this period (proxy depth 2.7 m), yet the proxy depth data was excluded from analysis.

The net sample depths were variable between sites and ranged from 0.8 to 2.7 m ($\bar{x}$ = 1.8 m) at RBDD Bypass Outfall and 1.7 to 2.8 m ($\bar{x}$ = 2.3 m) at Tehama Bridge (Table 4). Depths recorded for samples containing green sturgeon larvae ranged from 1.1 to 1.7 m ($\bar{x}$ = 1.6 m) at the RBDD Bypass Outfall and 2.1 to 2.5 m ($\bar{x}$ = 2.4 m) at Tehama Bridge. Surface velocities ranged from 1.4 to 1.9 ms^{-1} ($\bar{x}$ = 1.7 $m\ s^{-1}$) at the RBDD Bypass Outfall and 0.9 to 1.4 ms^{-1} ($\bar{x}$ = 1.1 $m\ s^{-1}$) at Tehama Bridge (Table 4). Surface velocities recorded for samples containing green sturgeon larvae ranged from 1.5 to 1.9 ms^{-1} ($\bar{x}$ = 1.7 $m\ s^{-1}$) at the RBDD Bypass Outfall and 1.0 to 1.4 ms^{-1} ($\bar{x}$ = 1.1 $m\ s^{-1}$) at Tehama Bridge.

One hundred and twenty-two positively identified green sturgeon larvae were captured during the 2010 standard sampling period. Sixty-two larvae were sampled from the RBDD Bypass Outfall (RK 391) and 60 from Tehama Bridge (RK 369). Larvae were sampled over a 99 day period between May 6 and August 12, 2010. Samples were collected on 19 and 20 dates within this period from RBDD Bypass Outfall and Tehama Bridge, respectively (Figure 10). Ninety-two percent of the samples were collected from each location following the lowering of the RBDD gates. During the 99 day period of capture, 28 days were not sampled due to weekend non-sample days and RBDD operations associated with the lowering of the dam gates on June 15, 2010. No samples were lost this year due to gear failure and overall sampling of the 2010 season was discontinued on the night of August 28, 16 days after the last larva was captured (Figure 10).

Total length of larvae sampled ranged from 24 to 35 mm ($\bar{x}$ = 27 mm). Of 122 fish sampled, 38 were mortalities and 84 were in good condition (Table 5). Twenty-five fish were transferred to the USBR river laboratory for use in the UCD juvenile habitat use study (NMFS 2009). All morts were analyzed to determine estimated spawn dates and developmental stage using Dettlaff et al. (1993). Estimated spawn dates for 36 mort samples collected between June 4 and August 9, 2010 were between May 6 and July 7, 2010.

Experimental larval sampling surveys.— On May 18/19, June 22/23 and May 20/21, June 29/30, concurrently deployed gear was used to sample for green sturgeon larvae at RK 424.5 and RK 377, respectively. The D-net and two fyke nets were deployed at or near sunset on each occasion and sampled until dawn. No green sturgeon larvae were sampled at either site on any occasion by either gear type. One green sturgeon egg was sampled on the night of May 19 at RK 424.5 by the D-net. As noted in the egg mat sampling results section, 10 green sturgeon eggs were sampled from this site earlier in the day (Table 2).

Discussion

Through the sampling and positive identification of green sturgeon eggs using artificial substrate mats, five spawning areas in the Sacramento River were confirmed in 2010. Eggs were sampled for the third consecutive season from the Sacramento River at RK 424.5 and RK 377, for the second season at RK 407.5 and for the first time at RK 426 and RK 366.5. Green sturgeon eggs were sampled on multiple occasions from multiple spawning events (Table 2) at two of the five spawning sites. Eighty-eight percent more eggs were sampled in 2010 (N = 105) in comparison to 2009 (N = 56) and 150% more than 2008 (N = 42). However, the majority of eggs in 2010 (N = 90) were sampled at RK 424.5 on six occasions over a 20 day period (Figure 2).

Egg sampling surveys above RBDD.— Initiation of sampling was based on the results of the 2008 and 2009 surveys and the presence of fish detected by side scan sonar in the upper Sacramento River in early to mid-March of 2010. Eggs were first collected from RK 424.5, 33.5 river kilometers above the RBDD, 65 days before the lowering of the RBDD gates which creates a barrier to upstream migrating sturgeon (Brown 2007). Green sturgeon eggs were first collected 23 days following the initial egg mat deployment at RK 424.5. An egg was believed to have been found on April 2, but was not secured during storm weather conditions and could not be confirmed.

A total of 93 green sturgeon eggs were sampled from RK 424.5 between April 11 and May 27, 2010. These data indicate spawning occurred above RBDD only before the RBDD gates were lowered on June 15, 2010 (Figure 4). Spawning period in 2010 had to be estimated based primarily on collection date due to the damaged nature of eggs at the beginning and end of the collection period. Overall, the analyzed eggs collected above RBBD were estimated to be from at least 12 different spawning events within a six and a half week period all prior to the June 15 RBDD gate closure (Table 2).

All three sites chosen for sampling above RBDD in 2010 sampled at least one green sturgeon egg. The newest site at RK 426 added a nominal 1.5 river kilometers to the distance above RBDD that spawning was confirmed. Green sturgeon have been observed in similar types of habitat upstream of this point. Future sampling efforts should continue to seek confirmation of additional spawning areas to determine the uppermost spawning site within the Sacramento River system. Additional funding would be needed to embark on that endeavor.

Currently, spawning has been confirmed 35 river kilometers above the RBDD and at three specific sites as a result of the 2010 sampling efforts. A fourth, unplanned site, at RK 410.5 was sampled 15 times with two egg mats between May 21 and July 17 at the request of UCD researchers. These researchers, focusing on adult migration patterns, had detected large congregations of green sturgeon; including acoustic tagged adults implanted in 2010, holding and repeatedly moving in and out of this area (M. Thomas, UCD, pers. comm.). This unplanned site had swift water velocities, suitable depth, and varied substrates that were predominantly hardpan bedrock on river right (outside bend) and gravels and sand on river left (inside bend of river). No eggs were sampled and three egg mats were lost rendering effort at this site of little value. As this was not originally planned to be sampled, data from this site was excluded from analysis.

***Egg sampling surveys at RBDD*.—**The RBDD gates were again lowered a month later than recent years on June 15 due to new regulations imposed, in part, to aid the passage of green sturgeon adults to upper Sacramento River spawning habitat (NMFS 2009). Zero eggs were sampled by egg mats placed just downstream of gate 3 and 4's abutments where two green sturgeon eggs had been detected in 2009 (Poytress et al. 2010) and one in 2008 (Poytress et al. 2009). Four egg mats sampled this area for a period of 33 days with no green sturgeon egg samples detected. Green sturgeon were observed breaching in the area by USFWS field crews. Moreover, acoustic data collected by USBR and UCD determined green sturgeon visited the site, some repeatedly, as they "ping ponged" between this and other upstream and downstream aggregations (R. Corwin, USBR, pers. comm. and M. Thomas, UCD, pers. comm.) and confirmed spawning sites. Although no eggs were detected by egg mats during this period, one newly hatched larva (20 mm total length) was sampled by rotary traps adjacent to egg mats on July 14, 2010. This data point indicates that spawning did occur at the RBDD, yet was not detected by egg mat sampling efforts. Unfortunately, analysis of the larva proved unsuccessful to estimate spawning date, but the assumption can be made that this larva was the result of spawning that occurred in the first week of July as it would require 7 to 14 days to hatch given the ambient water temperatures (Deng et al. 2002).

***Egg sampling surveys below RBDD*.—** In contrast to the previous two years of sampling, the minority of green sturgeon eggs sampled in 2010 (9.5%; $N = 10$) were sampled below RBDD at RK 377 ($N = 9$) and RK 366.5 ($N = 1$; Table 2). The single egg collected at RK 366.5 confirms a fifth spawning site in 2010 and a sixth spawning site overall in the Sacramento River. This new site, 10.5 river kilometers downstream of the previously confirmed lowest downstream spawning site (RK 377), translates into an overall distance of 60 river kilometers of spawning habitat identified in the Sacramento River. Moreover, the new site was 24.5 river kilometers below the RBDD. Future sampling efforts should continue to seek confirmation of spawning areas to determine the lowermost spawning site within the Sacramento River system. Additional funding would be needed to embark on that endeavor.

Eggs were sampled from RK 377, for the third year in a row, but much more sporadically and in lower numbers than in previous years. The first egg was sampled on April 27, 2010. No other eggs were sampled from this site until 44 days later on June 10, 2010. The majority of eggs sampled from this site were sampled over a six day period from June 10 through June 16, 2010 (Figure 5) and believed to have been produced from three different spawning events (Table 2). Eight eggs were sampled from this site prior to the RBDD gates being lowered and only one egg was discovered following the gate closure (Figure 5). The total spawning period at RK 377, based on the nine eggs collected, was just over seven weeks (50 days).

Overall, the spawning area at RK 377 appeared to have been changed in 2010 compared to the 2008 and 2009 sampling seasons. The winter of 2010 produced much greater stage and discharge rises on the Sacramento River than the prior two years. The water year index was recorded as “Below Normal” for 2010, but was better than the “Dry” and “Critically Dry” designation listed for the Sacramento Valley in 2009 and 2008, respectively (http://cdec.water.ca.gov/cgi-progs/rpts/WSI). Sacramento River discharge exceeded 1,700 m^3s^{-1} on one occasion in January and it is hypothesized that the magnitude of this type of event affected the overall substrate composition and hydraulics of the RK 377 spawning site. Alternately, large numbers of green sturgeon were detected above the RBDD this year which may indicate habitat preference in light of the later RBDD gate closure or a behavioral response to the spring storm discharge events (Figures 4, 5).

Spawning substrate surveys.— UVC surveys conducted of pools at RK 426, RK 424.5, RK 423, and RK 366.5 revealed the full range of substrate types present within each site relative to the hydraulic components present (Figures 6-9). However, within the micro-habitats where eggs were collected at RK 426, RK 424.5, and RK 366.5, pockets of small to medium gravel were consistently observed amongst generally larger substrate. These findings bolster observations made by Poytress et al. (2009) and (2010) which states eggs were consistently collected over small to medium sized gravel at RK 424.5, RK 407.5, RK 391, and RK 377.

Survey results reported by Poytress et al. (2009) from May 22, 2008 indicate the substrate at RK 424.5 consisted of medium sized gravel with lesser amounts of cobble and sand. Since that survey, mild winter storms, associated runoff, and low lake levels at Shasta Dam prevented river elevations from reaching monitoring stage at RK 424.5 during the 2009 and 2010 water years. River channel alterations are unlikely at these flows as a bedrock river left bank inhibits river channel migration. Results from the 2010 survey closely mimicked that of the previous survey conducted in 2008. Although winter and spring peak flows during the 2009 and 2010 water years did not cause large scale changes in the substrate, they appear to have transported smaller sized substrates into the pool. Relatively lower, regulated summertime flows tend to gradually redeposit the transported gravel to the tail out areas of the pools (Dunne and Leopold 1978).

Further downstream at RK 377 during the 2010 water year the river elevation reached within 0.5 meters of flood stage on two occasions during the month of January. The high river flows eroded the river left bank behind the man-made levee seemingly changing the surface hydraulics of this pool. Egg collection from what is perceived to be an important spawning site dropped off significantly in 2010 compared to the previous two years. Conducting substrate surveys in both April and July of each year coupled with egg collection data may provide insight into how variable these spawning micro-habitats are and how green sturgeon respond to in-season changes to spawning areas.

It was not known whether higher annual discharge, a delay in RBDD gate closures allowing greater access by green sturgeon to upstream spawning areas, site fidelity to upstream spawning areas by 2010 year class spawners, or substrate changes within the RK 377 pool reduced the utilization of this spawning site in 2010. Continued Sacramento River green sturgeon research and monitoring, keeping in mind the potential for considerable annual changes to spawning micro-habitats, needs to be considered until critical spawning site selection variables can be fully determined and parsed out from spawning behavior attributes.

Spatial and temporal distribution patterns of larvae.— Greater success was achieved using a benthic D-net to sample young of the year green sturgeon larvae in 2010 compared to the previous two years. One hundred twenty-two green sturgeon larvae were sampled at the RBDD Bypass Outfall and Tehama Bridge (Table 4). Larvae had previously only been collected at RBDD Bypass Outfall which is directly below a confirmed green sturgeon spawning location at RBDD (Brown 2007; Poytress et al. 2009, 2010). For the first time, larvae were sampled over a period of three months at two locations (Figure 10). Samples were collected at both locations beginning in May and ending in August. The first capture on May 6, 2010 at the RBDD Bypass Outfall (RK 391) occurred 25 days earlier than at Tehama Bridge (RK 369). Sampling of the last larva at RBDD Bypass Outfall occurred 10 days prior to the final capture at Tehama Bridge on August 12, 2010 (Figure 10).

The 2010 larvae collection results are consistent with the temporal pattern of egg captures noted by this project in the last three years (Poytress et al. 2009, 2010). Eggs have consistently been sampled at the furthest upstream sites prior to the first samples collected below RBDD in 2008-2010. These data may indicate that spawning and subsequent migration of larvae occurs earlier in the upper portions of the spawning reach compared to the lower sections. We speculate that some members (i.e., females) of this population exhibit a high degree of fidelity to specific spawning sites or reaches of the river. Alternately, some members or proportion of the population could be highly conditioned to reach the upper reaches of the Sacramento River prior to being blocked by the RBDD which, until recently, had blocked further upstream migration by mid-May.

The temporal distribution pattern suggested by the 2010 data indicates a nearly identical pattern exhibited by captures in the rotary screw traps at RBDD (Figure 10). Although consistent with the RBDD Bypass Outfall sample site (located 500 meters downstream of the rotary traps at RBDD), the pattern is very consistent in trend and magnitude for the Tehama Bridge captures as well (Figure 10). Poytress et al. (2010) stated that benthic “D-nets sample newly emerging larvae most effectively in close proximity to spawning grounds”. Samples of green sturgeon larvae from the Tehama Bridge in 2010 are believed to be derived from the closest upstream confirmed spawning location at the mouth of Antelope Creek (RK 377), a distance of over eight river kilometers. Little habitat similar to where eggs have been sampled appears to exist between Tehama Bridge and the mouth of Antelope Creek. It is possible that spawning is occurring closer to the Tehama Bridge than we are aware of, but most of the habitat between these two areas consists of riffle/run and shallow water complexes less than five meters in depth. Furthermore, no fish have been observed breaching, present during scans with side-scan sonar units, or holding in these areas as part of mobile tracks or during multi-year acoustic telemetry studies of green sturgeon in this reach (R. Corwin, USBR and M. Thomas, UCD, pers. comm.). These data in combination with the captures of green sturgeon larvae prior to the RBDD gates being lowered (which creates a quasi natural spawning site each year), may refute the statement that D-nets are most effective for sampling in close proximity to spawning areas. Nonetheless, it is entirely reasonable to assume that we have not located all of the spawning areas within one to two river kilometers of the larvae sample sites and we may have had success at Tehama Bridge in 2010 due to being relatively close to an undocumented spawning area.

Standard and experimental larval sampling effort.— Overall, standard sampling effort was more concentrated, consistent, and greater in total wetted net time compared to prior years. The employment of a hydraulic driven winch resulted in zero down time due to equipment failure, in stark contrast to prior years. This allowed us to sample the originally planned five nights per week for a period of four months. Total CPUE was 0.005 green sturgeon larva per minute of sampling in 2010 for all sites and sample types combined (Table 4). This rounded value was identical to the one reported from the 2009 sampling effort; although total effort and catch were roughly a third in that year. Thirty-six percent of 2009 green sturgeon larvae captured were derived from exploratory sampling on a single night and heavily influenced the annual total (Poytress et al. 2010). The 2010 sampling effort consistently captured fish over a four month period.

Exploratory sampling in 2010 proved unsuccessful for larvae capture with either gear type (D-net or fyke), yet 225% more effort was afforded. The reasons for this are not fully understood, but it is suspected that the exploratory sampling events in May were too early for larval migration as only a single green sturgeon egg was collected (Table 4). Interestingly, the second exploratory event occurred after larvae had been sampled in the standardized sampling work at both locations, but no larvae were captured between June 9 and July 6 at either location or by the exploratory sampling events that occurred on June 22/23 and June 29/30. Furthermore, no larvae were sampled by rotary traps between June 19 and July 7 (excluding June 15-18 when traps were not sampling; Figure 10). It is hypothesized that young of the year larvae ceased migration during this time as no captures occurred during the full moon phase in June to July. Larvae were collected during subsequent full moon phases, albeit a small percentage of the total captures. It is probable that these fish, being of such small size (Table 4), exhibited negative phototactic behavior similar to that observed in the lab (Kynard et al. 2005).

Nocturnal distribution patterns.— The laboratory observations of greater activity of green sturgeon larvae in the night time period (Van Eenennaam et al. 2001; Kynard et al. 2005) and migration activity of multiple sturgeon species at or near the river bottom (Kohlhorst 1976; LaHaye et al. 1992; Schaffter 1997; Auer and Baker 2002; and Deng et al. 2002) was a primary motivation to sample the benthos exclusively during nocturnal hours. Although standard D-net sampling occurred primarily between the hours of 20:00 and 01:00 each night, the protocol employed in 2010 called for sampling to cease one hour after the last green sturgeon capture, when applicable. As a result of the implementation of this protocol, sampling on many occasions continued until near sunrise and nocturnal distribution patterns were observed to be similar to that reported in Poytress et al. (2010). Data from both sites was compared and equally showed a bi-modal distribution pattern (Figure 11). Larvae were sampled increasingly between the hours of 21:00 and 00:00 with a peak between the hours of 00:00 and 01:00. A second smaller peak was observed between the hours of 04:00 and 05:00 (Figure 11). These data coupled with the overall temporal distribution pattern are consistent with lab observations made by Kynard et al. (2005) while studying initial migrations of larval green sturgeon.

Sample comparison of targeted and non-targeted larval surveys.— Green sturgeon larvae samples collected by D-net at two sites and rotary traps at RBDD revealed a number of similarities. Already noted above, there was a striking similarity in the temporal distribution pattern of captures between the two gear types and three sites. A simple comparison of total catch between the RBDD (N = 70), the RBDD Bypass Outfall (N = 62), and the Tehama Bridge (N = 60) confirms that nocturnal sampling appears to be the appropriate time to catch young of the year green sturgeon on their initial migration (Kynard et al. 2005). It is interesting to note that the relative area of river water sampled by the two gear types is, at minimum, 20 times greater with the four rotary trap array at RBDD as compared to the relatively small D-net.

The median size of green sturgeon sampled by both gear types was found to be identical at 27 mm total length. A comparison of the total length distributions of the D-net larvae samples and rotary trap samples found no significant statistical size difference between collection methods (Kolmogorov-Smirnov Two Sample Test; df = 191, P = 0.306). Moreover, the median size of larvae sampled between the RBDD Bypass Outfall and Tehama Bridge, a distance of 22 river kilometers, was identical at 27 mm total length (Table 4). These data do not suggest growth is occurring between the two sites. Moreover, the consistent, relatively small size of fish sampled from our efforts indicates that we are only sampling larvae as they initially disperse from egg incubation and hatching areas (Kynard et al. 2005). It is likely that our sampling efforts are not capturing a true downstream migration to juvenile rearing and overwintering areas which was suggested by Kynard et al. (2005) to occur in the fall as water temperatures decreased below 10°C. Additional sampling effort in the fall and winter for green sturgeon juveniles migrating downstream could acquire data to confirm what was noted in the lab and provide essential information on the basic life history of green sturgeon.

Impacts of research and monitoring.— Of considerable concern, especially amongst regulating and permitting entities, is the issue of take and incidental mortality of Threatened

Sacramento River green sturgeon. As noted in NOAA's *Sturgeon Research Protocols for Shortnose, Atlantic, Gulf and Green Sturgeons* (Kahn and Mohead 2010), sampling of early life stages using D-nets assumes 100% mortality but "can be non-lethal". Sampling of this delicate life stage of fish is difficult to perform without deleterious effects to individuals.

The 2010 data collected by the USFWS found some interesting similarities and differences in the mortality of individuals sampled by D-nets and rotary traps. For instance total mortality associated with the 2010 D-net sampling was 31%, including those individuals that were sampled and found to be in poor physical condition (i.e., later sacrificed). Upon further inspection of the data, the 31% mortality value was highly skewed as a result of the RBDD Bypass Outfall site (89%) compared to 11% originating from the Tehama Bridge site (Table 5). The considerable difference was likely attributed to the rougher conditions larvae experienced in sample gear with the higher water velocities sampled at RBDD (Table 4) and the corresponding longer distances the net had to be deployed to sample correctly in those velocities. The distances averaged 24 meters and 15 meters for RBDD Bypass Outfall and Tehama Bridge, respectively.

Incidental mortality values related to USFWS RBDD rotary trapping over 15 years have historically been highly variable ranging from 0.74% to 54.1% ($\bar{x}$ = 10.8%) annually. The value for 2010 rotary trap sampling was 25.7%. Overall, the catch data does indicate that sampling can be non-lethal but greater than 50% (Table 5). Because of this non-lethal assumption, some larvae samples were planned on and able to be transferred to USBR facilities at RBDD (Table 5) for use in additional research to be conducted by UCD (NMFS 2009). Furthermore, incidental mortality specimens were provided to UCD for genetics testing (Israel et al. 2004) and can be used for kinship reconstruction and estimating breeding population size (Israel and May 2010).

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Tables

Table 1. Summary of green sturgeon egg sampling effort in wetted mat days (wmd; one sampler set for 24 hours), total number of green sturgeon eggs sampled by site (GST Eggs) and catch per unit effort (CPUE) at six sites on the upper Sacramento River, CA.

Location	Habitat	Start Date	End Date	Egg Mats (*N*)	Sample Effort (wmd)	GST Eggs	CPUE (eggs/wmd)
Ink's Creek (RK 426)	Pool	3/17/10	7/23/10	4	346.7	1	0.003
Massacre Flats (RK 424.5)	Pool	3/17/10	7/23/10	4	312.6	93	0.298
Turkey Beach (RK 407.5)	Pool/Glide	3/17/10	7/23/10	2	202.5	1	0.005
RBDD (RK 391)	Dam[a]	6/22/10	7/25/10	4	128.1	0	0.000
Antelope Creek (RK 377)	Pool	3/23/10	7/25/10	4	418.0	9	0.022
Red Barn (RK 366.5)	Pool	3/23/10	7/25/10	4	427.8	1	0.002
			Total	**22**	**1,835.7**	**105**	**0.057**

[a] Unconventional microhabitat at quasi-natural site; directly downstream of RBDD below dam gate hydraulics.

Table 2. Summary of estimated spawn date/time for green sturgeon egg samples collected in the upper Sacramento River, CA. Estimated spawn date and time was back calculated based on stage of embryogenesis (Dettlaff et al. 1993), developmental rates of green sturgeon (Deng et al. 2002), and mean daily Sacramento River water temperatures. Comments describe additional information related to developmental stage of the embryo.

Date	Location	Egg Count	Estimated Spawn Date	Estimated Spawn Time	Stage	Comments
4/11/10	RK 424.5	1	-	-	-	mottled color/not viable
4/11/10	RK 424.5	1	-	-	-	damaged during handling, viable but could not stage
4/27/10	RK 377	1	-	-	-	mottled color/not viable
5/5/10	RK 424.5	1	5/4/10	7:30pm	9	7-8th cleavage
5/5/10	RK 424.5	1	5/5/10	5:30am	5	just starting 2nd cleavage
5/5/10	RK 424.5	1	5/5/10	3:30am	6	3rd cleavage (8 cell)
5/5/10	RK 424.5	1	-	-	-	mottled/crushed (no dia),
5/5/10	RK 424.5	1	5/4/10	10:30pm	7-8	16-32 cell
5/5/10	RK 424.5	1	5/5/10	12:30am	7	16 cell
5/5/10	RK 424.5	1	5/5/10	2:30am	6-7	8-16 cell
5/5/10	RK 424.5	1	5/4/10	4:30pm	10	late cleavage
5/5/10	RK 424.5	1	-	-	-	mottled color/not viable
5/5/10	RK 424.5	1	5/5/10	6:30am	4	2 cell
5/5/10	RK 424.5	1	5/5/10	6:30am	4	2 cell
5/5/10	RK 424.5	1	5/5/10	2:30am	6-7	8-16 cell
5/5/10	RK 424.5	1	5/5/10	6:30am	4	2nd cleavage just starting
5/5/10	RK 424.5	1	5/4/10	4:30pm	10	late cleavage
5/7/10	RK 424.5	1	5/6/10	7:30pm	9	7-8th cleavage
5/7/10	RK 424.5	1	5/6/10	2:30pm	10	late cleavage
5/7/10	RK 424.5	1	5/6/10	2:30pm	11	late cleavage-early blastula
5/7/10	RK 424.5	1	5/6/10	2:30pm	11	late cleavage-early blastula
5/7/10	RK 424.5	1	-	-	-	viable, but mottled/crushed, no accurate diameter or stage
5/7/10	RK 424.5	1	5/5/10	4:30am	19	early neurulation
5/7/10	RK 424.5	1	-	-	-	mottled color/not viable
5/7/10	RK 424.5	1	5/6/10	4:30pm	10	late cleavage
5/7/10	RK 424.5	1	5/6/10	1:30am	15	mid-gastrulation
5/7/10	RK 424.5	1	-	-	-	viable, but bulging yolk, no accurate diameter or stage
5/7/10	RK 424.5	1	5/6/10	2:30pm	11	late cleavage-early blastula
5/7/10	RK 424.5	1	5/6/10	2:30pm	11	late cleavage-early blastula

Table 2 Continued.

Date	Location	Egg Count	Estimated Spawn Date	Estimated Spawn Time	Stage	Comments
5/7/10	RK 424.5	1	5/6/10	2:30pm	11	late cleavage-early blastula
5/7/10	RK 424.5	1	5/5/10	4:30am	19	early neurulation
5/7/10	RK 424.5	1	5/6/10	2:30pm	11	late cleavage-early blastula
5/7/10	RK 424.5	1	-	-	-	not viable/bulging
5/7/10	RK 424.5	1	-	-	-	not viable/bulging
5/7/10	RK 424.5	1	-	-	-	not viable
5/7/10	RK 424.5	1	5/6/10	6:30am	13	early gastrulation
5/7/10	RK 424.5	1	5/5/10	4:30am	19	early neurulation
5/7/10	RK 424.5	1	5/5/10	4:30am	19	early neurulation
5/7/10	RK 424.5	1	5/6/10	6:30am	13	early gastrulation
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula
5/7/10	RK 424.5	1	5/5/10	4:30am	19	early neurulation
5/7/10	RK 424.5	1	-	-	-	crushed (no accurate dia)
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula, partly crushed
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula
5/7/10	RK 424.5	1	-	-	-	no etoh in vial cannot verify viability/stage/diameter
5/7/10	RK 424.5	1	-	-	-	crushed
5/7/10	RK 424.5	1	-	-	-	crushed/marbled
5/7/10	RK 424.5	1	-	-	-	crushed/marbled
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula
5/7/10	RK 424.5	1	5/6/10	12:30pm	11	late cleavage-early blastula
5/7/10	RK 424.5	1	-	-	-	crushed
5/7/10	RK 424.5	1	5/5/10	10:30pm	16	large yolk plug
5/7/10	RK 424.5	1	5/6/10	6:30am	13	early gastrulation
5/7/10	RK 424.5	1	5/6/10	1:30am	15	mid-gastrulation
5/7/10	RK 424.5	1	5/6/10	1:30am	15	crushed/ no accurate diameter; parts of stage 15 visible
5/7/10	RK 424.5	1	-	-	-	unfertilized (some parthenogenic cleavage)
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula

Table 2 Continued.

Date	Location	Egg Count	Estimated Spawn Date	Estimated Spawn Time	Stage	Comments
5/7/10	RK 424.5	1	-	-	-	crushed/marbled
5/7/10	RK 424.5	1	-	-	-	crushed/marbled
5/7/10	RK 424.5	1	5/6/10	10:30am	12	late blastula
5/7/10	RK 424.5	1	5/6/10	6:30am	13	early gastrulation
5/10/10	RK 424.5	1	-	-	-	crushed/marbled
5/10/10	RK 424.5	1	-	-	-	crushed/marbled
5/10/10	RK 424.5	1	5/8/10	10:30am	17	small yolk plug
5/10/10	RK 424.5	1	5/8/10	10:30am	17	small yolk plug
5/10/10	RK 424.5	1	5/8/10	10:30am	17	small yolk plug
5/10/10	RK 426	1	5/4/10		32-33	pre-hatch larva; chorion broke in handling,13.34 mm TL
5/11/10	RK 366.5	1	-	-	-	either just fertilized or unfertilized, too early to verify
5/18/10	RK 407.5	1	-	-	-	crushed/marbled
5/19/10	RK 424.5	1	5/19/10	5:30am	5	4-cell
5/19/10	RK 424.5	1	5/19/10	5:30am	5	4-cell
5/19/10	RK 424.5	1	5/19/10	6:30am	4	2 cell
5/19/10	RK 424.5	1	5/19/10	7:30am	3	grey crescent
5/19/10	RK 424.5	1	-	-	-	unfertilized
5/19/10	RK 424.5	1	5/18/10	1:30am	15	mid-gastrulation
5/19/10	RK 424.5	1	5/18/10	9:30am	13	early gastrulation
5/19/10	RK 424.5	1	-	-	-	crushed/marbled
5/19/10	RK 424.5	1	-	-	-	mottled color/not viable
5/19/10	RK 424.5	1	5/17/10	4:30pm	17	small yolk plug
5/21/10	RK 424.5	1	5/20/10	1:30pm	11	late cleavage-early blastula
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage

Table 2 Continued.

Date	Location	Egg Count	Estimated Spawn Date	Estimated Spawn Time	Stage	Comments
5/21/10	RK 424.5	1	5/20/10	4:30pm		crushed
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/21/10	RK 424.5	1	5/20/10	4:30pm	10	late cleavage
5/24/10	RK 424.5	1	-	-	-	fungus covered
5/24/10	RK 424.5	1	5/21/10	1:00am	26	tailbud, heart forming
5/24/10	RK 424.5	1	-	-	-	fungus covered
5/24/10	RK 424.5	1	-	-	-	unfertilized
5/27/10	RK 424.5	1	-	-	-	fungus covered
6/10/10	RK 377	1	-	-	-	marbled
6/10/10	RK 377	1	-	-	-	crushed
6/13/10	RK 377	1	6/13/10	5:30am	5	4-cell
6/13/10	RK 377	1	-	-	-	unfertilized
6/13/10	RK 377	1	6/13/10	2:30am	6	8-cell, broken, no accurate diameter
6/13/10	RK 377	1	6/12/10	4:30pm	10	late cleavage
6/13/10	RK 377	1	6/13/10	3:30am	6	8-cell, broken, no accurate diameter
6/16/10	RK 377	1				crushed/marbled
	Total	**105**				

Table 3. Summary of egg mat sample depths and green sturgeon egg sample depths recorded during the 2010 green sturgeon egg mat sampling season.

		Sample Depths (m)			GST Egg Sample Depths (m)		
Sample Location	**Microhabitat**	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
Ink's Creek (RK 426)	Pool	1.7	6.6	14.0	8.9	8.9	8.9
Massacre Flats (RK 424.5)	Pool	1.7	6.4	14.4	4.2	7.1	10.9
Turkey Beach (RK 407.5)	Pool/Glide	2.9	8.3	11.0	9.7	9.7	9.7
RBDD (RK 391)	Dam[a]	0.8	1.2	1.6	-	-	-
Antelope Creek (RK 377)	Pool	1.4	4.5	13.9	2.4	3.6	6.1
Red Barn (RK 366.5)	Pool	3.7	6.0	14.5	6.2	6.2	6.2

[a]Unconventional microhabitat at quasi-natural site; directly downstream of RBDD below dam gate hydraulics.

Table 4. Benthic D-net sample effort, green sturgeon catch, catch per unit effort (CPUE), median total length (TL), net depth and surface velocities for samples collected during the 2010 green sturgeon larvae sampling project on the Sacramento River, CA.

Sample Type	Sample Site	Effort (min)	GST Catch	CPUE	TL (mm)	Depth (m)			Velocity (m/sec)		
						Min	Ave	Max	Min	Ave	Max
Standard	RBDD Bypass Outfall (RK 391)	11,792	62	0.005	27	0.8	1.8	2.7	1.4	1.7	1.9
Standard	Tehama Bridge (RK 369)	12,462	60	0.005	27	1.7	2.3	2.8	0.9	1.1	1.4
Experimental	Massacre Flats (RK 424.5)	1,077	0[a]	0.000	-	1.9	2.5	2.7	0.8	1.0	1.1
Experimental	Mouth of Antelope Creek (RK 377)	1,053	0	0.000	-	2.0	2.7	3.0	0.9	0.9	0.9
	Total	**26,384**	**122**	**0.005**							

[a] No green sturgeon larvae, but one confirmed green sturgeon egg sampled during the May 19, 2010 sampling effort.

Table 5. Disposition of 2010 green sturgeon larvae sampled by benthic D-net and rotary screw traps in the upper Sacramento River, CA.

			Mortality		Live	
Sample Gear	**Sample Site**	**Total**	**Direct**	**Sacrifice**[a]	**Transfer**[b]	**Release**
Benthic D-net	RBDD Bypass Outfall (RK 391)	62	33	1	12	16
Benthic D-net	Tehama Bridge (RK 369)	60	2	2	13	43
Rotary screw trap	RBDD (RK 391)	70	18	0	17	35

[a] Larvae sacrificed were euthanized as determined to be unlikely to recover from sampling stress.
[b] Larvae transferred to U.S. Bureau of Reclamation facilities for further research to be conducted by University of California Davis (NMFS 2009).

Figures

2010 Green Sturgeon Sampling Locations

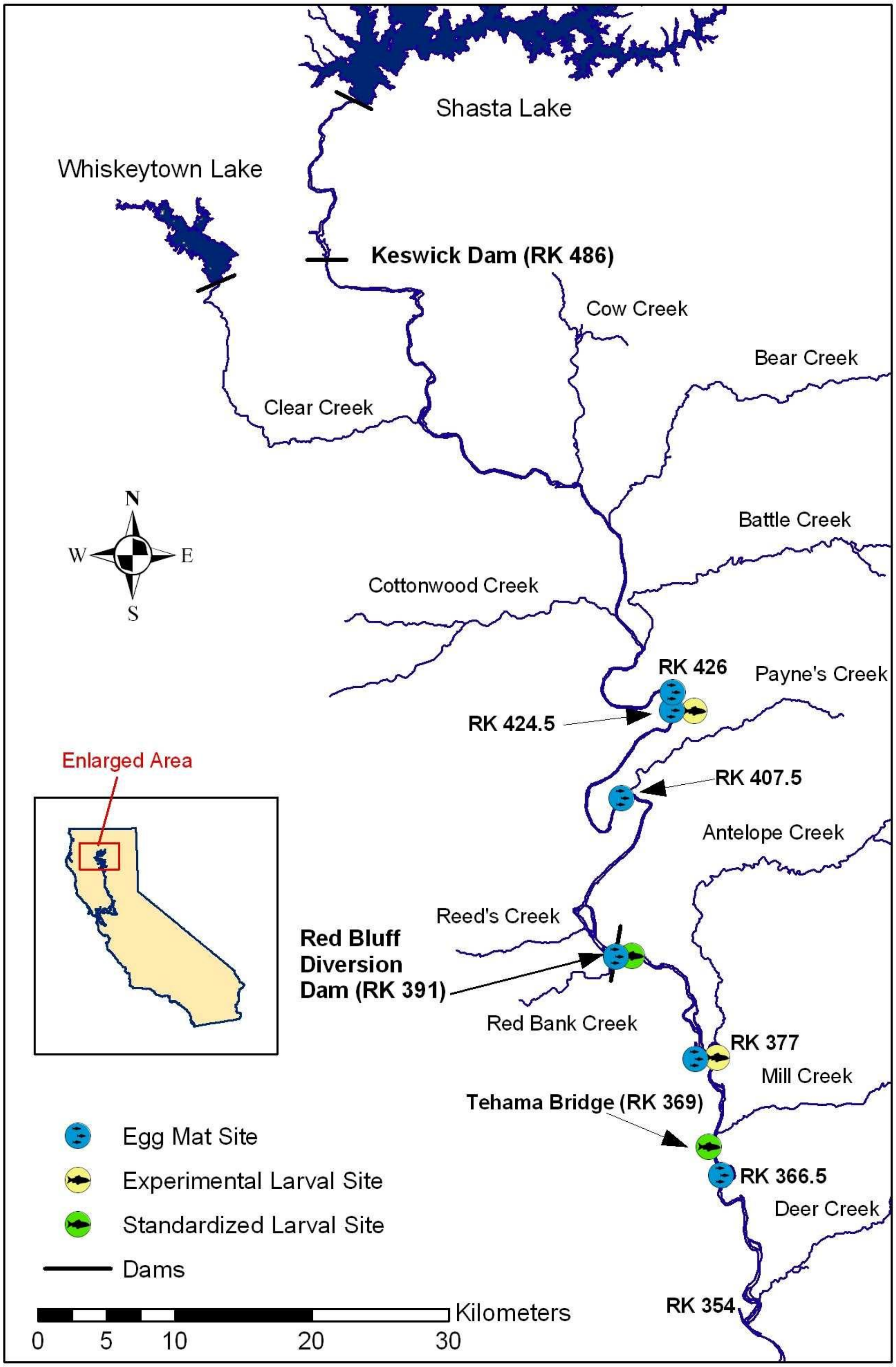

Figure 1. Green sturgeon egg and larval sample sites in the upper Sacramento River, CA.

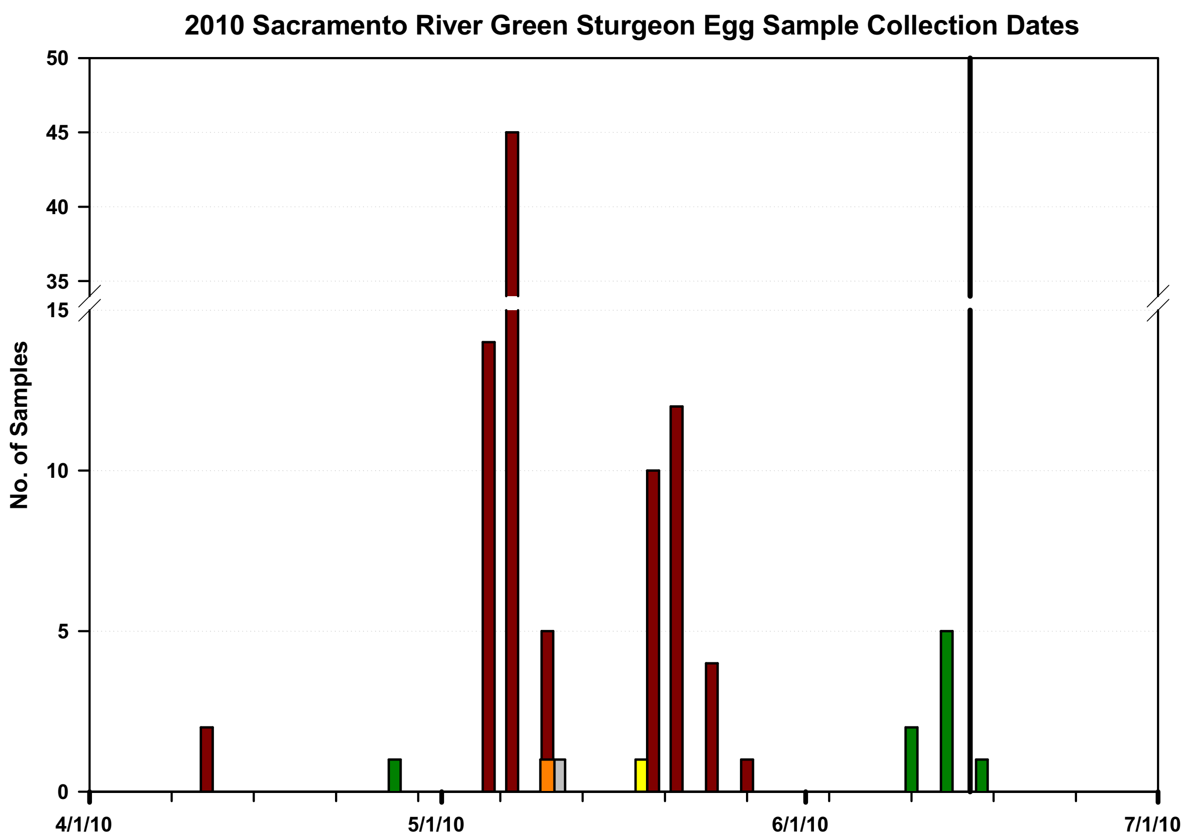

Figure 2. Temporal distribution of green sturgeon egg samples collected at Ink's Creek (RK 426; orange bar), Massacre Flats (RK 424.5; red bars), Turkey Beach (RK 407.5; yellow bar), Antelope Creek (RK 377; green bars), and Red Barn (RK 366.5; gray bar) on the Sacramento River, CA. Black vertical line indicates RBDD gate closure on June 15, 2010.

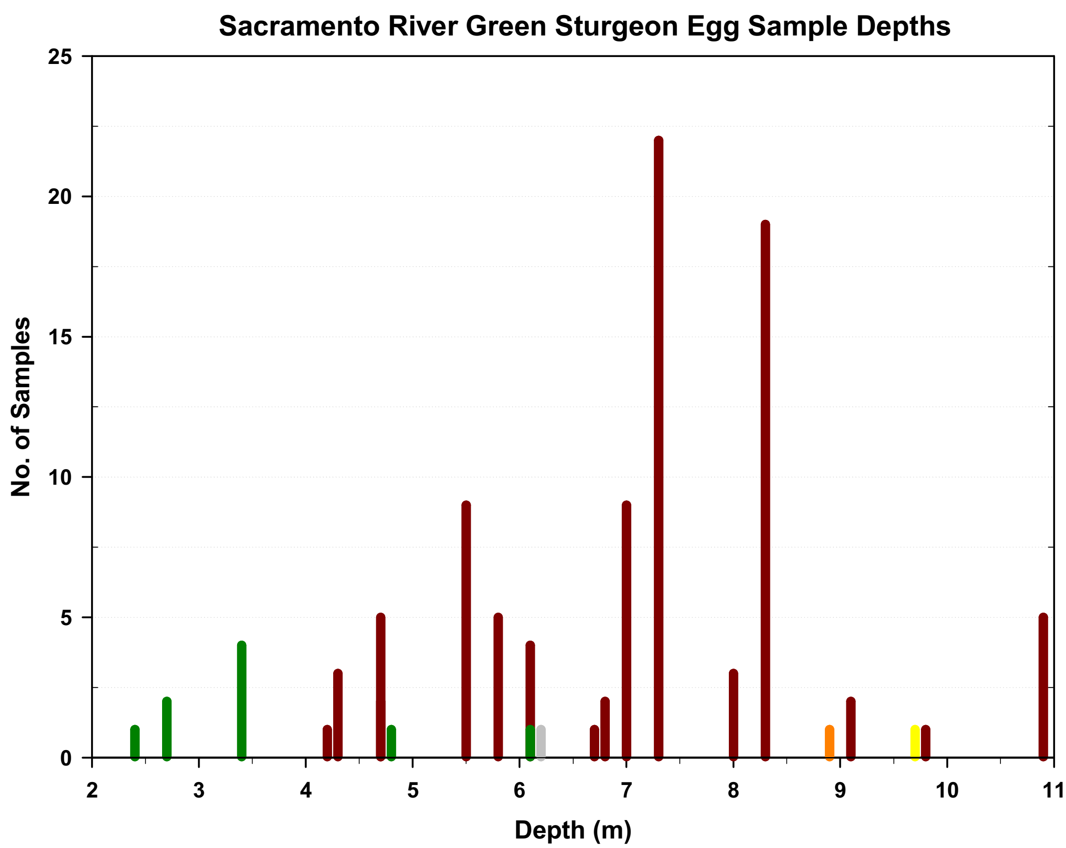

Figure 3. River depths of green sturgeon eggs sampled from egg mats at Ink's Creek (RK 426; orange bar), Massacre Flats (RK 424.5; red bars), Turkey Beach (RK 407.5; yellow bar), Antelope Creek (RK 377; green bars), and Red Barn (RK 366.5; gray bar) on the Sacramento River, CA for the period April 11 - June 16, 2010.

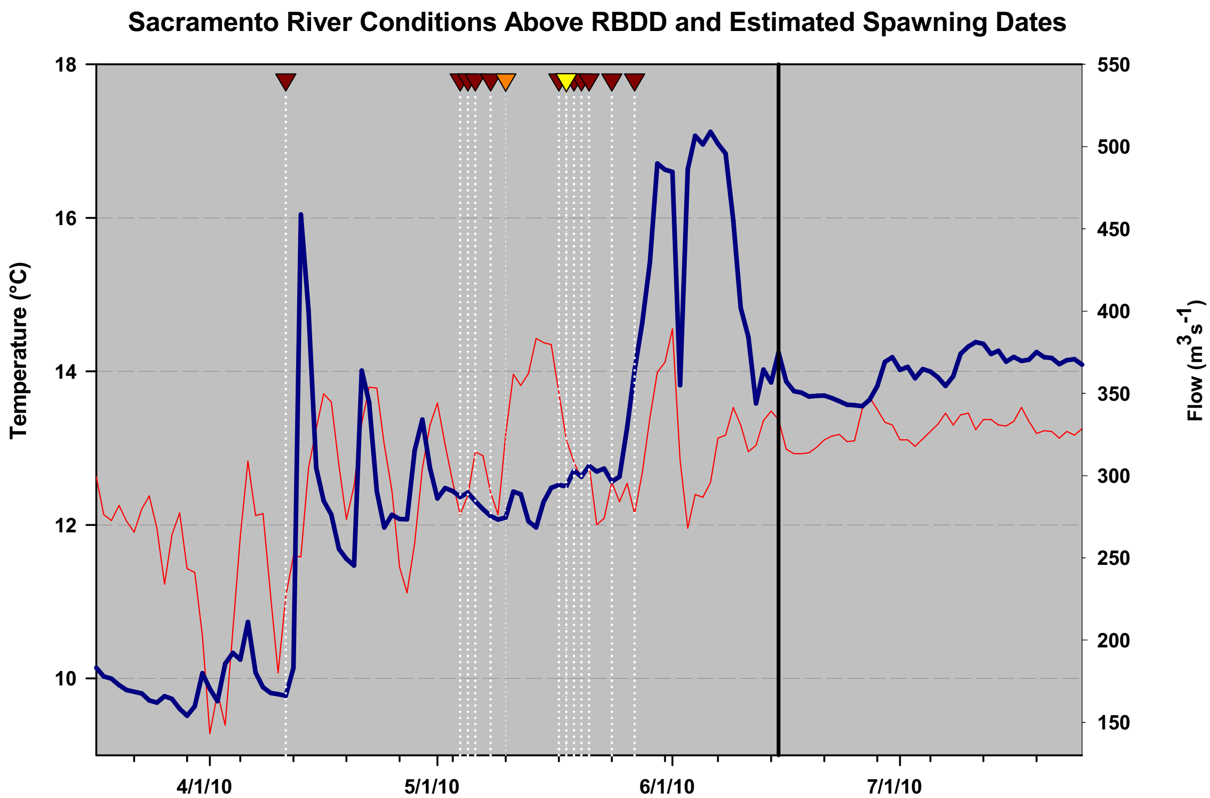

Figure 4. Sacramento River mean daily flow (dark blue), and mean daily temperature (red) at Bend Bridge Gauging Station. Inverted triangles indicate estimated spawning dates for Ink's Creek (RK 426; orange), Massacre Flats (RK 424.5; red) and Turkey Beach (RK 407.5; yellow). Black vertical line indicates RBDD gate closure on June 15, 2010.

Sacramento River Conditions Below RBDD and Estimated Spawning Dates

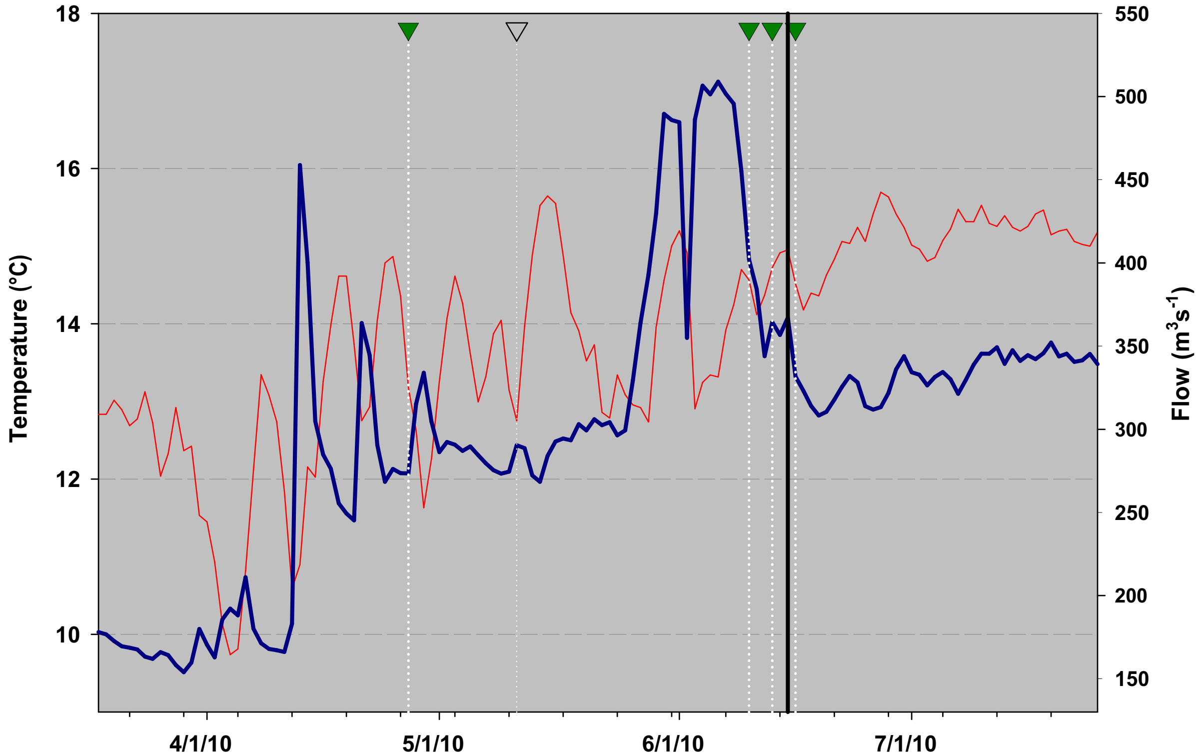

Figure 5. Sacramento River mean daily flow (dark blue), and mean daily temperature (red) at Bend Bridge Gauging Station minus daily diversions at RBDD (when applicable). Inverted triangles indicate estimated spawning dates for Antelope Creek (RK 377; green), and Red Barn (RK 366.5; gray). Black vertical line indicates RBDD gate closure on June 15, 2010.

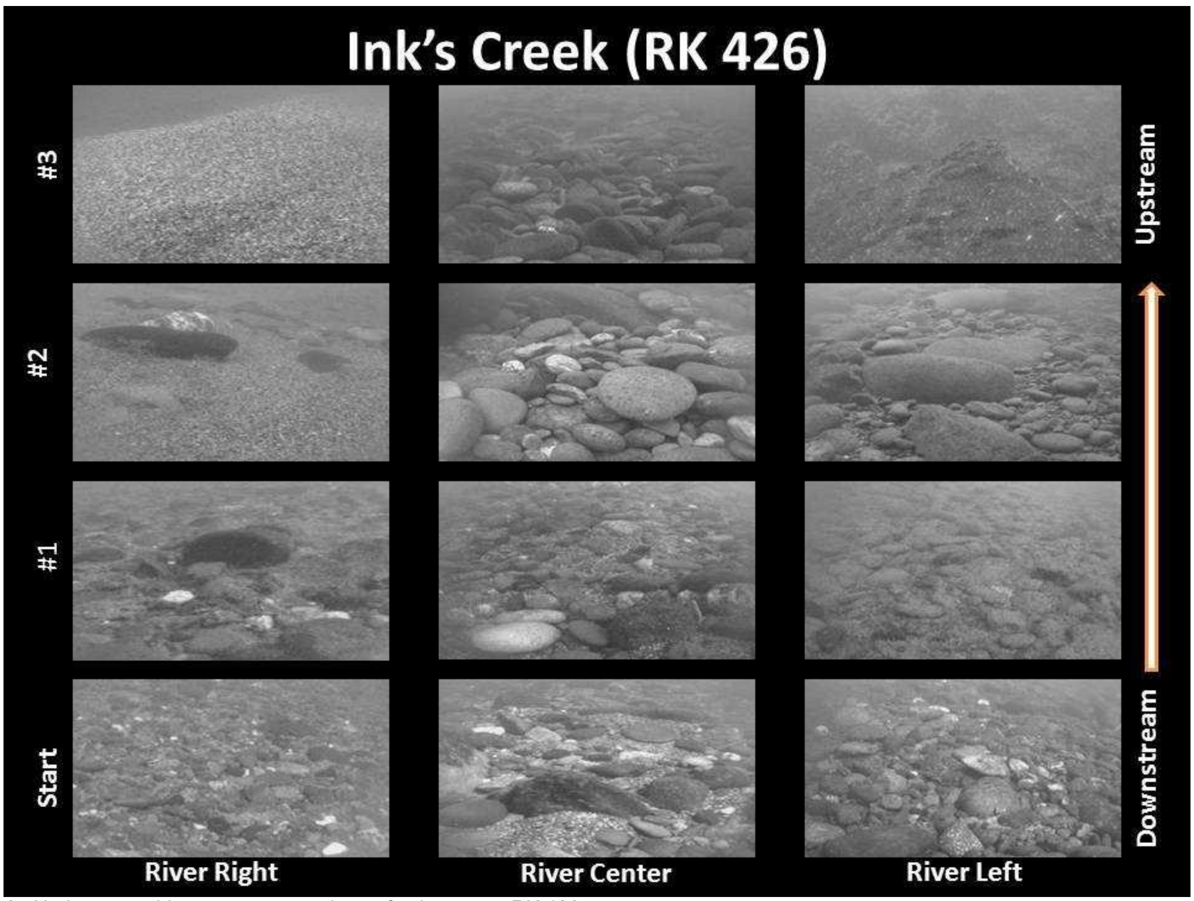

Figure 6. Underwater video camera snapshots of substrate at RK 426.

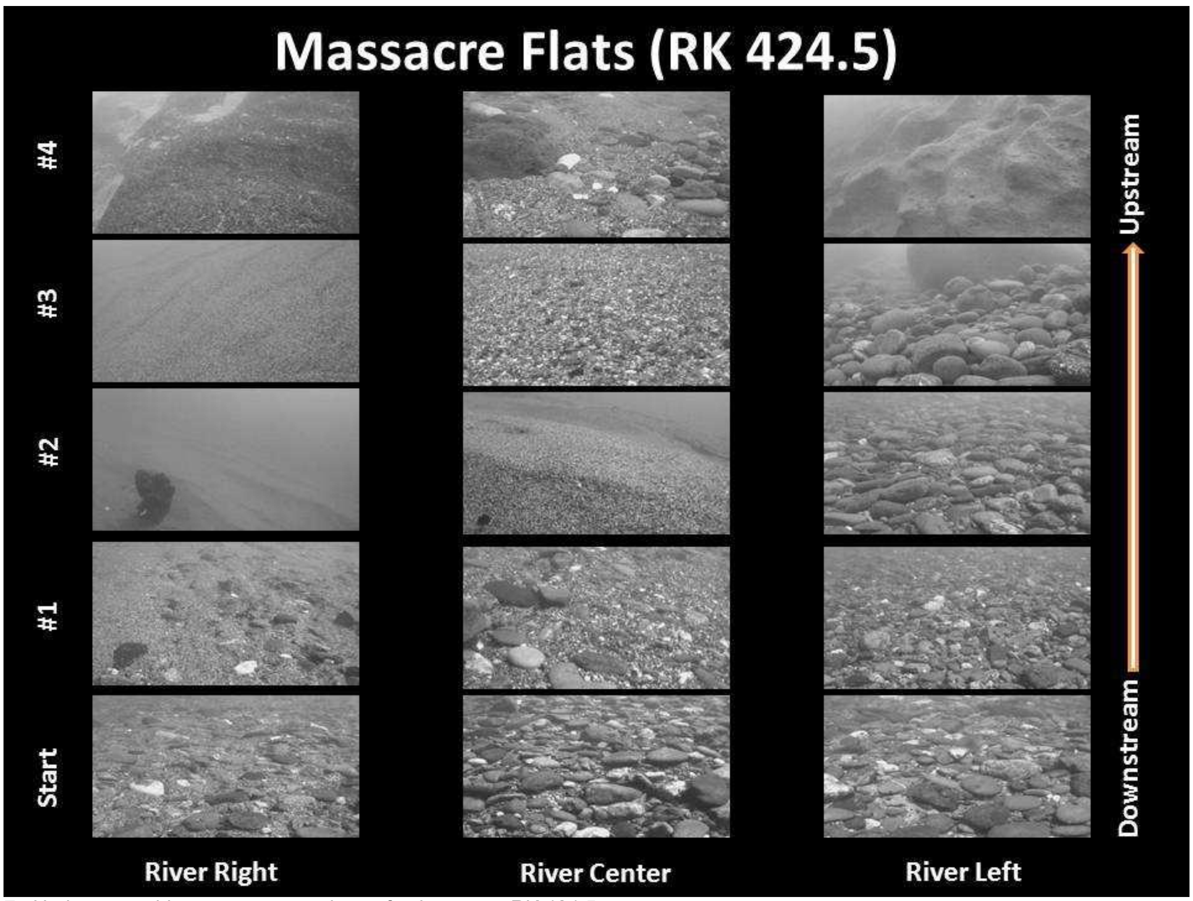

Figure 7. Underwater video camera snapshots of substrate at RK 424.5.

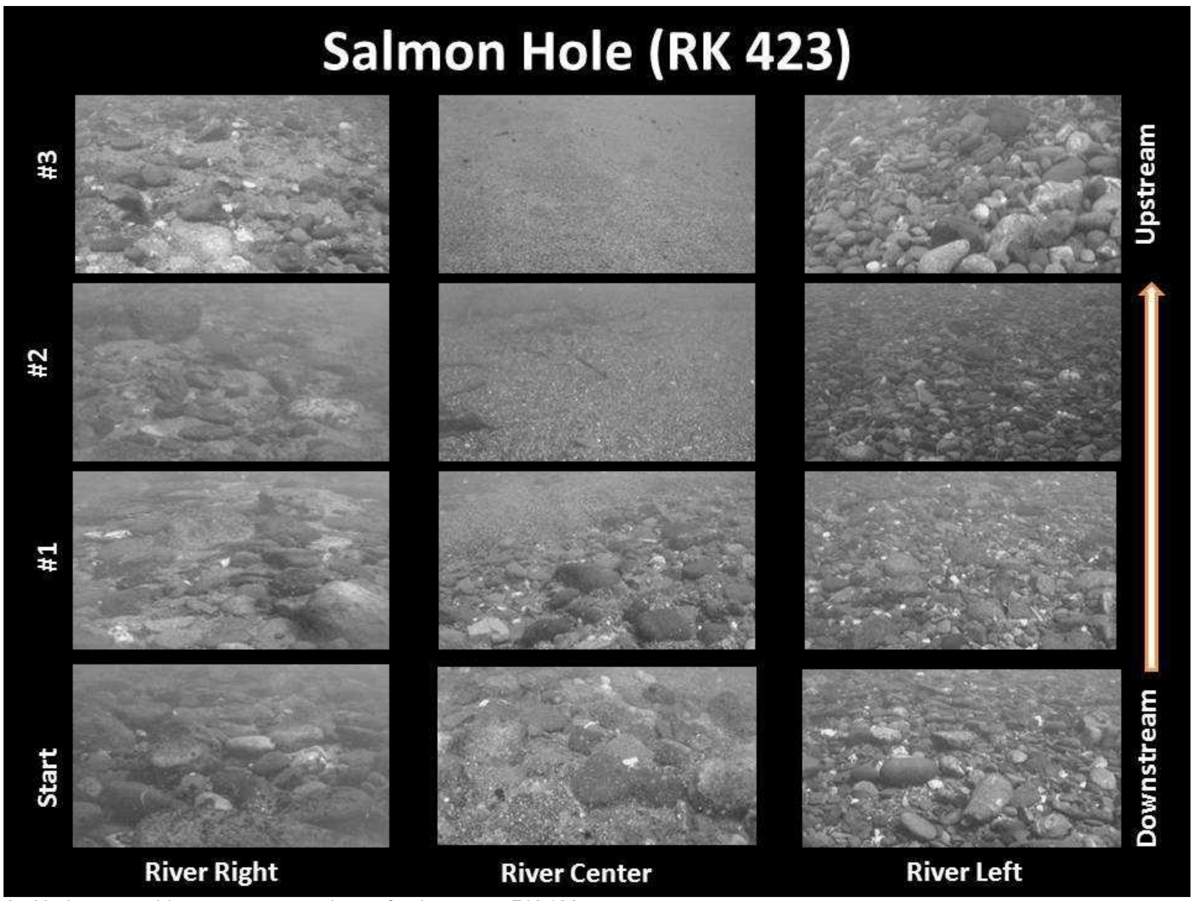

Figure 8. Underwater video camera snapshots of substrate at RK 423.

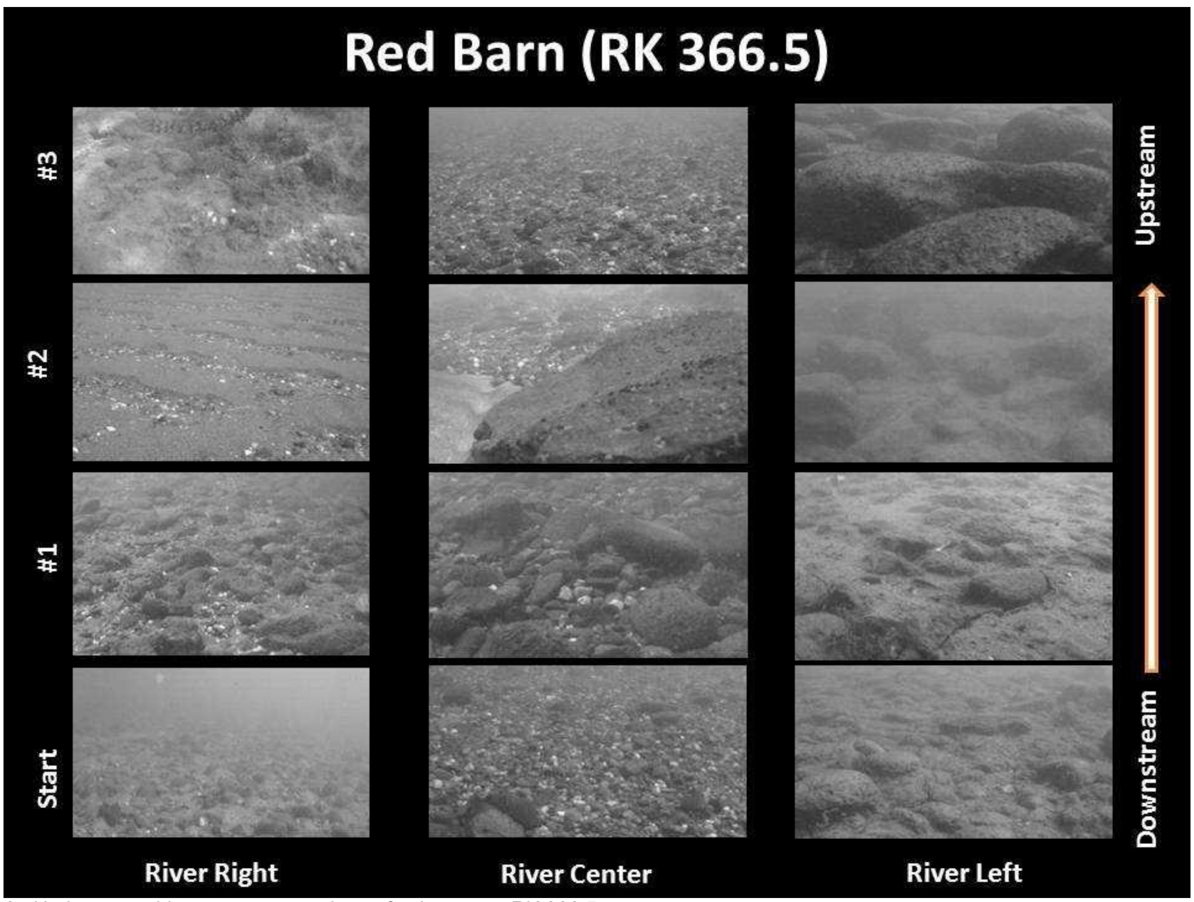

Figure 9. Underwater video camera snapshots of substrate at RK 366.5.

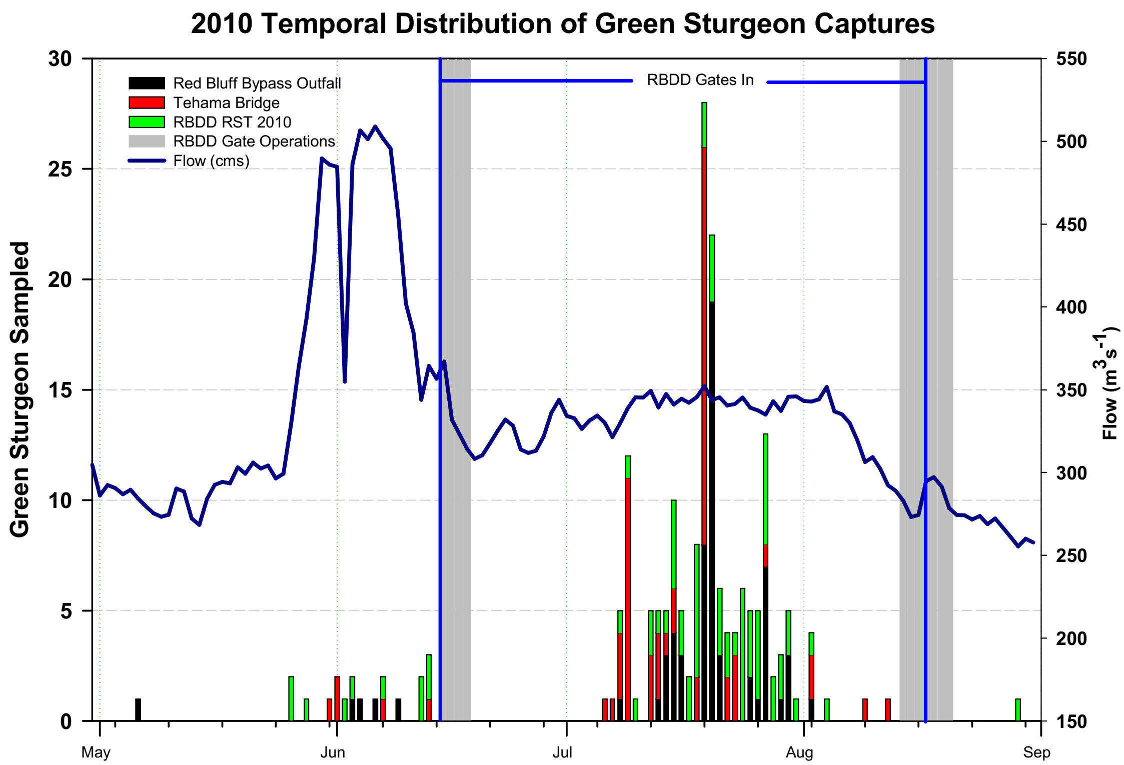

Figure 10. Green sturgeon larvae sampled by benthic D-net and rotary screw-trap for the period April 28 through August 28, 2010. Samples were collected from the RBDD Bypass Outfall (black bars), Tehama Bridge (red bars) and RBDD (green bars). Sampling occurred at the RBDD Bypass Outfall and Tehama Bridge alternating nights; typically Sunday through Thursday of each week. Rotary trapping occurred seven days per week except between June 15 - 18 and August 14 -20 due to operations associated with the RBDD (gates in/out).

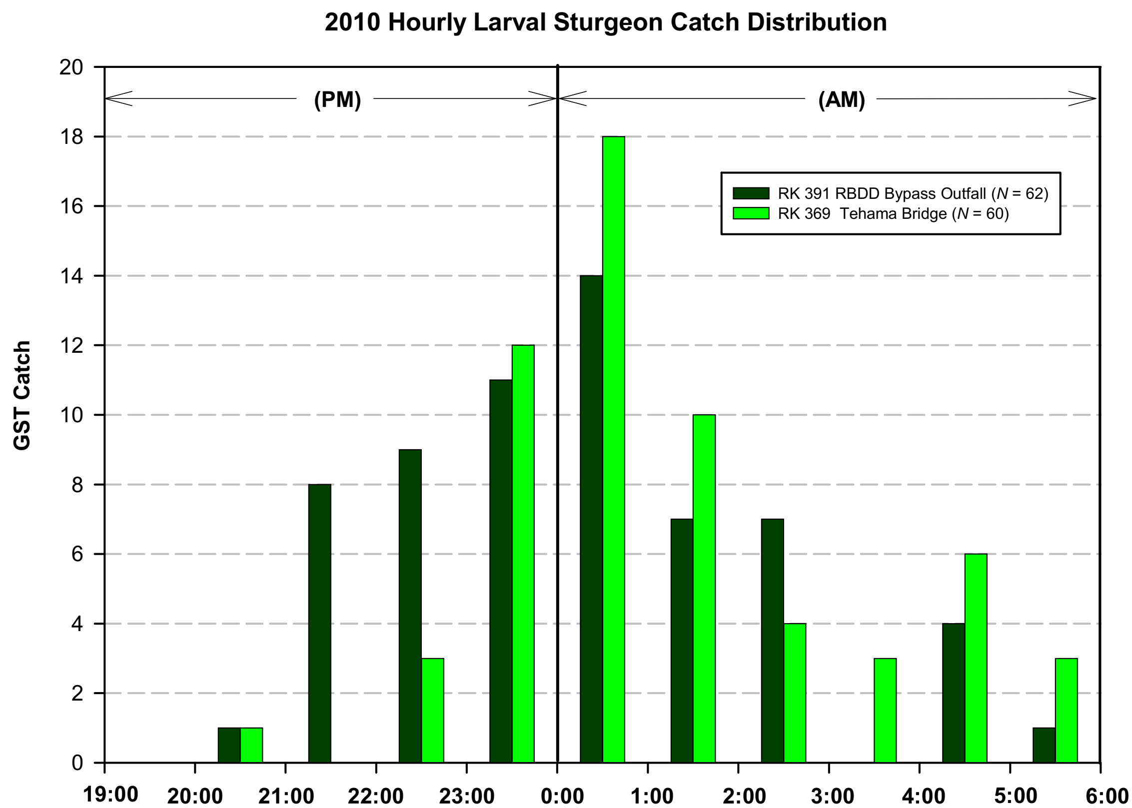

Figure 11. Nocturnal distribution pattern comparison for cumulative annual total of green sturgeon captures at RBDD Bypass Outfall (RK 391; dark green bars) and Tehama Bridge (RK 369; light green bars).