2011 UPPER SACRAMENTO RIVER GREEN STURGEON SPAWNING HABITAT AND LARVAL MIGRATION SURVEYS

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Disclaimer

Cover Photo: Multiple green sturgeon larvae sampled on July 21, 2011 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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2011 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys

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***Abstract.*—** Through the sampling and positive identification of green sturgeon eggs using artificial substrate mats, three spawning areas in the Sacramento River were confirmed in 2011. Eggs were sampled for the second consecutive year from the Sacramento River at RK 426, for the third of four years at RK 391 (RBDD) and for the first year at RK 332.5. Far *fewer* eggs were sampled in 2011 (*N* = 11) compared to 2010 (*N* = 105), 2009 (*N* = 56) and 2008 (*N* = 42). Sampling conditions in the Sacramento River in 2011 were more difficult than previous years due to spring storms and variable discharge resulting in a three week delay in sampling. Water temperatures ranged from 11.2 to 14.6°C ($\bar{x}$ = 12.9°C) during the estimated spawning period. Over the last 4 years, on average, the depth eggs were collected at RBDD was 5.3 meters *less* than the other six sites where spawning has been confirmed. Multiple pass underwater video substrate surveys were performed within egg mat sampling sites at RK 338 and RK 332.5, post egg sampling. From 2008 through 2011, green sturgeon spawning habitat has been identified at seven locations covering a 94 river kilometer reach of the Sacramento River.

The greatest total capture of green sturgeon larvae in four seasons of effort was achieved using a benthic D-net in 2011. A combined 643 green sturgeon larvae were sampled from the RBDD Bypass Outfall (18.5%), Tehama Bridge (74.2%), and Gianella Bridge (8.3%). Larvae were sampled within a 95 day period between May 23 and August 25, 2011. Average sample depth and water velocity when green sturgeon larvae were collected was 1.7 meters and 1.0 ms^{-1}, respectively.

The temporal distribution pattern determined by four years of sampling indicates a nearly identical pattern exhibited by captures in the rotary screw traps at RBDD and D-net sampling. Directed sampling effort using D-nets for temporal distribution data should be discontinued in 2012 during the initial dispersal period provided rotary traps are in operation. Future D-net effort should focus on greater spatial distribution data as well as fall sampling when it is hypothesized that juvenile green sturgeon migrate to overwintering areas.

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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*, which was listed as threatened under the Federal Endangered Species Act on April 7, 2006 (BRT 205; NMFS 2006). Heightened concern by the U.S. Bureau of Reclamation (USBR) regarding the potential impacts of the Red Bluff Diversion Dam (RBDD) to green sturgeon prompted the initiation of a series of studies focused on determining how various life history stages of this population may be affected by current dam operations. From 2008 through 2011, 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.

Six spatially discrete SDPS green sturgeon spawning areas were confirmed on the Sacramento River, CA through egg sampling by the USFWS between 2008 and 2010 (Poytress et al. 2009-2011). 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 2011 green sturgeon egg and larval surveys.

Objectives

The objectives of this fourth-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 limited 2008-2010 confirmed spawning sites for repeated spawning site use, (3) monitor the environmental conditions of the sites where eggs were found and characterize spawning habitat in terms of water temperature, depth, river discharge, and substrate type, (4) determine the 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) 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 April 12 through September 9, 2011. This report includes data and information on green sturgeon spawning areas, spawning substrate surveys, and larval drift characteristics 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 draining numerous slopes of the Coast, Klamath, Cascade, and Sierra Nevada mountain ranges and eventually reaches the Pacific Ocean via 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 as it flows south to the Sacramento-San Joaquin Estuary.

Sampling was concentrated within a 105 river kilometer reach of the Sacramento River from the mouth of Ink's Creek (RK 426) to Gianella Bridge (RK 320.6) with RBDD roughly halfway in between (Figure 1). The 2011 study area contained five previously confirmed spawning micro-habitats (Brown 2007; Poytress et al. 2009-2011). The study area was expanded downstream to include two indeterminate spawning micro-habitats associated with the presence of adult green sturgeon based on 2008 through 2011 acoustic telemetry data (R. Corwin, USBR and M. Thomas, UCD, unpublished data) and one previously documented adult holding area (Vogel 2008, Hublein et al. 2009). The study area in 2011, as described, provided five logistically feasible egg sampling locations both upstream (N = 2) and downstream (N = 3) of RBDD and three 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 allows 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 four locations on the Sacramento River commonly known as the mouth of Ink's Creek (RK 426), Massacre Flats (RK 424.5), Lone Oak (RK 338), and Glenn-Colusa Irrigation District (GCID) Hole (RK 332.5) upstream of the oxbow inlet channel (Figure 1). Mats were predominantly deployed in the within pool microhabitats (areas flanking deepest portions of pools) based on the results of the 2008 - 2010 studies (Poytress et al. 2009-2011). 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.

Four 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, 2011 due to regulations implemented in 2009, in part, to aid the passage of green sturgeon adults to upper Sacramento River spawning habitat (NMFS 2009). Egg mats were deployed downstream of partially opened dam gates (hydraulically active areas) generally flanking locations of observed sturgeon aggregations and activity.

Egg mat sampling consisted of visual inspection, generally twice a week, throughout the sample period. Paired egg mats were retrieved from the river, placed on a boat in a custom made egg mat carrier, and initially inspected on both sides by at least two field crew members. Egg mats were then rinsed with river water to remove debris and sediment and then re-inspected. Rinse water and debris were filtered using 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 inspection and inspection of the mesh nets, egg mats were redeployed.

Eggs collected from each mat were counted and identified to species 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 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 on egg collection date and developmental stage, then 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. Non-green sturgeon fish eggs were field identified using an egg key provided by Rene Reyes of the U.S. Bureau of Reclamation's Tracy Fish Salvage Facility (Reyes 2011). Non-fish eggs (e.g., amphibian), were noted and returned to the water or saved for laboratory examination.

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 UCD personnel. Sacramento River hourly flow data for the two 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 at RBDD were estimated using Bend Bridge data and subtracting daily diversions at RBDD (when applicable). Flows for the lowermost sites were obtained from the California Data Exchange Center's Vina-Woodson Bridge gauging station (http://cdec.water.ca.gov/cgi-progs/queryF?VIN). Sample effort data was calculated using the date and time individual egg mats were set and retrieved.

***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, mainstem rivers focusing on deep water spawning habitat of fall Chinook salmon (*Oncorhynchus tshawytscha*), lake trout (*Salvelinus namaycush*), and bottom dwelling burbot (*Lota lota*; Groves and Chandler 1999). Surveys were performed using a Deep Blue Pro color underwater video camera (UVC; 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. A second video camera (PC887WR) was focused on a Humminbird 1198c depth finder to record river depth, GPS coordinates, and side scan sonar imagery. Video images were recorded on a four channel 12 volt mobile DVR displayed in real-time on an 18 cm LCD monitor.

Surveys consisted of three longitudinal transects along river right, mid-channel, and river left at egg sampling sites. Each transect typically proceeded from the furthest downstream point to the upstream end of suspected sturgeon spawning areas at approximately 1-2 k/hr. The UVC was oriented upstream and kept within 30 cm of the river bottom so the substrate was clearly visible on the LCD monitor. At the end of each transect, the UVC was raised to the water surface or secured onboard within the deployment apparatus.

Each holding pool was surveyed for observation data including GPS location, time, substrate type, river depth, and notable above and below water physical features. 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 to designate specific microhabitats within each survey site. Individual transects were plotted using ESRI® Arc GIS 10. 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 through August, based on spawn timing (Brown 2007; Poytress et al. 2010) and juvenile outmigration timing (Gaines and Martin 2002). Larvae capture by RBDD rotary traps was used as an alternate guide to commence larval sampling in the absence of egg captures. Based on previous studies on the Sacramento River (Brown 2007; Poytress et al. 2009 - 2011) 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 01:00.

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 3.2 mm DuPont 66 nylon fiber mesh fashioned into a 3.0 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 6,620 ml PVC aquatic sample bucket (15.2 x 43.2 cm) was attached to the cod end allowing for easy access to collected samples. An additional layer of 1.6 mm Delta knotless netting was sewn inside the latter 45.7 cm of the 3.2 mm netting to prevent larval sturgeon from escaping prior to entering the collection bucket.

Steel bar stock was added to the base of the net frame to properly orient the net in the current and 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 steel aircraft cable 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, safe transit 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. 2009-2011) 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. 2009-2011).

Sampling effort was 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 larvae. Four bridge supports at Tehama Bridge allowed for multiple sampling locations however, the second bridge support was used as it was located in the thalweg (Poytress et al. 2010). At the RBDD Bypass Outfall, one river center tie-off existed for all sampling efforts. During standard sampling, the net was generally set to sample for 10, 20, or 30 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. 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. The river velocity was measured in the center of the mouth of the D-net during each sample using a General Oceanic® Model 2030 flowmeter. Set time was defined 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 to species, measured, and enumerated. Green sturgeon eggs were identified to species and enumerated then retained in 95% EtOH for laboratory examination and species identification. Non-sturgeon eggs were identified using the egg identification key provided by Rene Reyes of the U.S. Bureau of Reclamation's Tracy Fish Salvage Facility (Reyes 2011). 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 either 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 larval fish collected were visually identified to the genus level primarily in the field and in some cases in the lab.

Results

***Egg sampling surveys*.—** Egg mat sampling occurred between April 12 and July 18, 2011 (Table 1). RBDD mats were deployed on June 26, 2011, following the lowering of the dam gates on June 15, 2011, and sampled until July 29, 2011. Egg mats sampled a total of 1,243.4 wetted mat days (wmd; one mat set 24 hours; Table 1). Sampling effort among the five sites ranged from 119.6 to 309.4 wmd ($\bar{x}$ = 248.7 wmd; Table 1). During April (*N* = 1), May (*N* = 1), and June (*N* = 1) mats at all sites were retrieved for a period of one to seven days due to storm/flow events and redeployed one to eight days later. Five mats were lost or deemed irretrievable over the course of the sample season after being buried by sediment.

Between May 18 and June 29, 2011, eleven green sturgeon eggs were collected at RK 426 (*N* = 9), RK 391 (*N* = 1), and RK 332.5 (*N* = 1; Table 2). Egg samples were collected on five different sample days (Figure 2). Daily positive egg sample totals per site ranged from 1 to 4 ($\bar{x}$ = 2.2). All eggs sampled were collected on a single mat at each location.

Catch per unit effort (sturgeon eggs/wmd) ranged from 0.000 at Massacre Flats and Lone Oak site to 0.031 at the Ink's Creek site ($\bar{x}$ = 0.009). Catch per unit effort for all sites combined totaled 0.043 green sturgeon eggs/wmd (Table 1).

Six of eleven eggs (55%) were assessed for developmental stage and described using Detlaff et al. (1993). Two eggs (18%) could not be determined to have been fertilized and an additional two eggs appeared fertilized but dead. One egg was lost during processing. Embryonic developmental assessment indicated eggs were between stage 21 (early neurulation) and stage 35 (post-hatch larva). Based on date and location of capture, water temperature, stage of development, and the assumption that a female requires 12 to 20 hours to release all of her eggs, samples were likely collected from five different females who spawned between May 15 and June 26, 2011 (Table 2).

Egg diameter (width and length) was measured in the field prior to fixation and in the lab (post fixation) on 64% of the egg samples, albeit not the same seven samples. One egg collected at GCID hole was not measured in the field as all mats were being removed due to storm flows. The egg was subsequently measured in the lab. Additionally, one egg measured in the field was not preserved in good enough condition to be re-measured in the lab. Of the directly comparable measurements (*N* = 6), field width and length measurements ranged from 3.63 to 4.28 mm ($\bar{x}$ = 3.92 mm) and 3.99 to 5.10 mm ($\bar{x}$ = 4.91 mm), respectively. Laboratory width and length egg diameter measurements ranged from 3.76 to

4.21 mm ($\bar{x}$ = 3.97 mm) and 4.00 to 4.69 mm ($\bar{x}$ = 4.32 mm), respectively. Three very recently hatched embryo's sampled by egg mats on June 20, 2011 were approximately 13.2 mm in total length (post fixation).

Egg mats sampled in water depths ranging from 0.7 to 14.5 m ($\bar{x}$ = 5.7 m; Table 3). Sample depths for green sturgeon eggs collected from all three sites combined ranged from 2.0 to 11.1 m ($\bar{x}$ = 7.4 m; Figure 3).

High flows in March and early April resultant from flood control releases from Shasta Dam delayed the initiation of the 2011 egg sampling season by three weeks. During the sample period, five spring storm events between April and June resulted in hydrograph spikes that correspond with peak flow values noted at all sample sites. Sacramento River flows at RK 426 and RK 424.5 above RBDD ranged from 237 to 690 m^3s^{-1} ($\bar{x}$ = 370 m^3s^{-1}) during the sample period and 280 to 469 m^3s^{-1} ($\bar{x}$ = 421 m^3s^{-1}) at RK 426 during the estimated spawning period (Figure 4). Sacramento River flows at RBDD (RK 391) ranged from 326 to 397 m^3s^{-1} ($\bar{x}$ = 353 m^3s^{-1}) during the sample period and was 313 m^3s^{-1} when spawning was estimated to have occurred (Figure 5). Sacramento River flows upstream of the GCID diversion ranged from 306 to 746 m^3s^{-1} ($\bar{x}$ = 408 m^3s^{-1}) during the sample period and was 330 m^3s^{-1} when spawning was estimated to have occurred (Figure 6).

Mean daily water temperatures ranged from 10.8 to 14.7°C ($\bar{x}$ = 12.9°C) at RK 426 (Figure 4). Mean daily water temperatures ranged from 13.0 to 14.5°C ($\bar{x}$ = 14.0°C) at RBDD (Figure 5) and 11.6 to 17.1°C ($\bar{x}$ = 14.8°C) below RK 332.5 (Figure 6). During the estimated spawning period, water temperatures ranged from 11.1 to 14.4°C ($\bar{x}$ = 12.8°C) at RK 426, 12.8 to 14.5°C ($\bar{x}$ = 13.8°C) at RK 391 and 9.6 to 14.9°C ($\bar{x}$ = 12.2°C) below RK 332.5.

Instantaneous turbidity grab sample values from the above RBDD sites ranged from 1.3 to 21.2 nephalometric turbidity units (NTU) throughout the sample period ($\bar{x}$ = 5.3 NTU). During the estimated spawning period at RK 426, turbidity ranged from 4.2 to 7.7 NTU ($\bar{x}$ = 5.6 NTU). Instantaneous turbidity grab sample values from the RBDD site ranged from 2.6 to 4.4 NTU ($\bar{x}$ = 3.6 NTU) and 4.4 to 26.2 NTU ($\bar{x}$ = 7.9 NTU) for the lowermost (above GCID diversion) site throughout the sample period. During the estimated spawning period at RK 391 and RK 332.5, turbidity ranged from 4.8 to 26.2 NTU ($\bar{x}$ = 8.5 NTU).

***Spawning substrate surveys*.—** Multiple pass UVC surveys were performed within green sturgeon egg mat sampling sites at RK 338 and RK 332.5 on September 23, 2011 (Figure 7-8). Sacramento River discharge at the Vina-Woodson Bridge gauging station was 273 m^3s^{-1}. At RK 338, the river makes a sharp left bend deflecting off the leading edge of a levee directing the flow to the middle of the river creating the Lone Oak pool. Although high water velocity and turbulence were observed at this location, a limited number of small standing waves were found to be present. Surveys conducted at RK 338 showed the pool tail was comprised of scattered gravel and cobble embedded in sand (RR1-9; MC1-9; RL1-4; Figure 9). As each pass proceeded upstream, the substrate composition changed presumably due to the pool's hydraulic influences. Sand dominated the substrate and was suspended within the water column in the backwater eddies on either side of the pool and the upstream edge of the pool (RR9-13; MC9-16; RL4-10; Figure 9). Upstream of waypoint RR13, higher water velocity exposed patches of underlying hard pan, with substrate size increasing to gravel throughout the remainder of the river right pass. Gravel dominated the substrate within the thalweg (MC16-20) until the highest water velocity exposed hardpan at the head of the pool (MC21).

RK 332.5 contained areas of minor surface turbulence with no standing waves. A stable river right bank upstream of and including the survey area resulted in a 3.3 – 8.9 m deep channel throughout the survey area. Fine sand and detritus covered the shallowest section of the survey area (RR1; Figure 10). Substrate rugosity increased with water velocity, with sand giving way to gravel immediately downstream of waypoint RR6. The left side of waypoint RR6 photo shows mixed cobble substrate. A vein of homogenous gravel was found in the upper section of the river right pass (RR6-23) extending through the lower section of the mid-channel pass (MC1-16). The remaining portions of the survey area (MC16-25; RL1-21; Figure 10) consisted of sand, detritus and pockets of large woody debris.

***Larval migration surveys*.—** Larval drift sampling took place from May 23 to September 9, 2011. Wetted net time totaled 333.4 hours (20,004 minutes) during weekly standard sampling efforts (Table 4). The RBDD Bypass Outfall site was sampled every other night, typically between the hours of 20:00 and 01:00. Sampling at Tehama Bridge (RK 369) occurred on the alternate nights during the same time period. Net set times ranged from 4 to 49 minutes ($\bar{x}$ = 30.0 minutes). A third site at Gianella Bridge (RK 320.6) was implemented mid-season due to concerns regarding permitted take and incidental mortality rates associated with sampling the swift current at the RBDD Bypass Outfall site (RK 391). Sampling efforts at Gianella Bridge were kept at one night per week, with net set times ranging from 20 to 47 minutes ($\bar{x}$ = 31.9 minutes).

As previously noted, multiple storm/flow events occurred throughout the sampling season. Runoff and debris loads from the storm event in early June precluded sampling for a 6 day period during the first emigration of larvae (Figure 11). Sacramento River conditions beyond mid-June 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 3.1 to 18.3 NTU ($\bar{x}$ = 4.6 NTU), 3.2 to 54.6 NTU ($\bar{x}$ = 7.0 NTU) for the Tehama Bridge site and 3.5 to 4.6 NTU ($\bar{x}$ = 3.9 NTU) for the Gianella Bridge site. Debris loads from collected samples were generally light to moderate, typically consisting of detritus and aquatic vegetation.

Net sample depths for samples containing green sturgeon larvae varied among sites, and ranged from 1.5 to 2.1 m ($\bar{x}$ = 1.7 m) at RBDD Bypass Outfall, 1.6 to 2.8 m ($\bar{x}$ = 1.9 m) at Tehama Bridge and 1.3 to 1.6 m ($\bar{x}$ = 1.5 m) at Gianella Bridge (Table 4). Velocities measured at the mouth of the D-net for samples containing green sturgeon larvae ranged from 0.8 to 1.4 ms^{-1} ($\bar{x}$ = 1.3 m s^{-1}) at the RBDD Bypass Outfall, 0.8 to 1.1 ms^{-1} ($\bar{x}$ = 1.0 m s^{-1}) at Tehama Bridge, and 0.4 to 0.6 ms^{-1} ($\bar{x}$ = 0.6 m s^{-1}) at Gianella Bridge (Table 4).

Six hundred and forty-three green sturgeon larvae were captured during the 2011 sampling period. One hundred and nineteen larvae (18.5%) were sampled from the RBDD Bypass Outfall (RK 391), four hundred and seventy-seven (74.2%) from Tehama Bridge (RK 369), and forty-seven (8.3%) from Gianella Bridge. Larvae were sampled within a 95 day period between May 23 and August 25, 2011. Samples were collected on 7 of 31 dates within this period from RBDD Bypass Outfall, 20 of 31 dates from Tehama Bridge, and 5 of 9 dates from Gianella Bridge (Figure 11). Fifty-seven percent of all green sturgeon larvae were collected following the lowering of the RBDD gates. During the 95 day period of capture, sampling did not occur on 39 days (41%) due to weekend non-sample days, RBDD operations associated with the lowering of the dam gates on June 15, 2011, and reduced effort to stay within 4(d) permit take restrictions. No samples were lost due to gear failure. Overall sampling of the 2011 season was concluded on September 9, fourteen days after the last larva was captured (Figure 11).

Total length of larvae sampled ranged from 22 to 49 mm ($\bar{x}$ = 27 mm). Of 643 sturgeon sampled, 93 were direct mortalities, 17 were sacrificed due to presumed sample stress (i.e., not likely to recover) and 528 were released in good condition (Table 5). Five sturgeon were transferred to the USBR river laboratory for use in a UCD juvenile habitat study (NMFS 2009). Mortalities were analyzed to estimate green sturgeon spawn dates (Wang et al. 1985, Deng et al. 2002). Estimated spawning period, calculated from 110 mort samples collected between May 23 and August 5, 2011, were between April 21 and July 3, 2011. Mortality rates differed greatly among sites, ranging from 42% at RBDD Bypass outfall to 12.2% at Tehama Bridge to 4.3% at Gianella Bridge ($\bar{x}$ = 19.5%; Table 5).

Discussion

Three green sturgeon spawning areas were confirmed in the Sacramento River using artificial substrate mats in 2011. Eggs were sampled for the second consecutive year from the Sacramento River at RK 426, for the third of four years at RK 391 (RBDD) and for the first year at RK 332.5. Green sturgeon eggs were sampled on multiple occasions from multiple spawning events (Table 2) at one of the three sites. Far *fewer* eggs were sampled in 2011 (N = 11) in comparison to 2010 (N = 105), 2009 (N = 56), and 2008 (N = 42). However, sampling conditions in the Sacramento River in 2011 were more difficult than previous years due to spring storms and variable discharge resulting in a three week delay in sampling (Figures 4-6).

***Egg sampling surveys above RBDD*.—** Sampling was anticipated to begin mid-March, well before first egg sample collection dates in 2008 through 2010 (Poytress et al. 2009–2011). Initiation of sampling on April 12, 2011 was based on inability to conduct sampling at discharge levels above 570 m^3s^{-1}. Green sturgeon eggs were first collected 39 days following the initial egg mat deployment at RK 426 on May 27, 2011. Eggs were first collected from RK 426, 35 river kilometers above the RBDD, 19 days before the lowering of the RBDD gates which create a barrier to upstream migrating sturgeon (Brown 2007). A total of nine green sturgeon eggs were sampled from RK 426 between May 27 and June 20, 2011, indicating spawning occurred above RBDD before and after the RBDD gates were lowered on June 15, 2011 (Figure 4). However, estimates of spawn timing based on egg developmental analysis indicate three different spawning events within a four week period ending June 14, 2011 *prior* to the June 15 RBDD gate closure (Table 2).

For the first time in four years of sampling, no green sturgeon eggs were sampled from RK 424.5. Interestingly, acoustic monitoring and sonar data indicated a limited presence of green sturgeon adults in this pool in 2011 in contrast to prior years. Evidence of spawning at RK 426 in 2011 reconfirmed the use of this site by green sturgeon for spawning habitat. Future sampling efforts should continue to seek confirmation of additional spawning areas upstream of RK 426 to determine the uppermost spawning site within the Sacramento River system. DIDSON based acoustic surveys indicate a holding and possible spawning area near the mouth of Cow Creek at RK 451 (E. Mora, UCD, pers. comm.).

***Egg sampling surveys at RBDD*.—** Four egg mats sampled this site for a total of 120 wmd with one green sturgeon egg sample collected immediately after sampling of this site began on June 26, 2011. The single green sturgeon egg was sampled by mats placed just downstream of gate 3 and 4's concrete abutments in an area similar to where two eggs had been sampled in 2009 (Poytress et al. 2010). The USFWS green sturgeon egg surveys over the last 4 years have demonstrated that, on average, depth of eggs collected is 5.3 meters *less* at RBDD compared to the other six sites where spawning has been confirmed.

Construction of a new pumping plant to supply water to the Tehama Colusa Canal Authority is scheduled to be completed in the spring of 2012 and purportedly will eliminate the need to lower the RBDD gates ad infinitum (NMFS 2009). According to this plan, adult green sturgeon passage should no longer be compromised and free access to all parts of the Sacramento River will be unobstructed below Keswick Dam (RK 486) year round. As a result, it is indeterminate if spawning at the dam (Poytress et al. 2008-2011) in the last four consecutive years will continue without the dam in place. Poytress et al. (2009) hypothesized that the hydraulics and substrates below the dam mimic more natural confirmed spawning sites but with potentially increased rates of predation on eggs and larvae as has been confirmed with other anadromous species (e.g., juvenile Chinook; Vogel et al. 1988, Tucker et al. 2003).

If construction of the new pumping plant at the RBDD site is completed and no extension of the lowering of the RBDD gates is requested (NMFS 2009), 2011 may be the last year that green sturgeon spawn at RBDD. It will be interesting to note if spawning is attempted in this area in 2012 without the dam gates lowered. Egg sampling plans for 2012 will attempt to determine if spawning continues to occur or is abandoned at this site. This could indicate significant site fidelity or behavioral conditioning. In recent years, acoustic telemetry based data (R. Corwin, USBR, pers. comm.) has recorded adult green sturgeon "ping-ponging" between this area and other confirmed spawning sites upstream and downstream of the dam during late May to mid-June when the gates have traditionally been closed for the last 45 years.

The potential loss of the RBDD spawning site, which has been suggested to have differential success rates between the east and west sides of the river (Poytress et al. 2010), will likely be overshadowed by the free access adults will have to nearly 100 additional kilometers of potential spawning area upstream of RBDD. Furthermore, the ability for adults to safely navigate upstream of this area and "ping-pong" back to lower river sites without the threat of direct mortality (by migrating downstream under the formerly lowered dam gates) should result in an overall net benefit to the SDPS green sturgeon.

Future monitoring of the effects of the pumping plant on larval sturgeon passing the intake facility of the pumping plant is highly recommended. Sampling of 'screened' water at the forebay during night time periods may also shed light on screening efficiency of the new "Chinook friendly" screens. Additional video based survey work of the new screens could also better determine potential impacts to larval sturgeon passing this pumping facility. Finally, green sturgeon larval monitoring using rotary traps at RBDD may be an effective way to determine if production upstream of the plant can successfully migrate past the new facility in terms of simple presence and absence catch data.

***Egg sampling surveys below RBDD*.—** The single egg collected at RK 332.5 confirms a seventh spawning site overall in the Sacramento River between 2008 and 2011. The egg sampled at RK 332.5 was the first egg sampled of the season with an estimated spawn date of May 15, 2011, a month prior to the RBDD gates being lowered. This newest site at RK 332.5, 58.5 river kilometers below the RBDD, resulted in an additional 34 river kilometers of the Sacramento River containing confirmed spawning habitat. Since 2008 and including 2011 data, green sturgeon spawning habitat has been identified within a 94 river kilometer reach of the Sacramento River. Future sampling efforts should reconfirm this site with additional samples and continue to determine the lowermost spawning site within the Sacramento River system during alternate water year types. Spring outflow and subsequent river water temperatures may be a vital factor affecting the distribution and success rate of SDPS green sturgeon spawning in the middle or lower reaches of the Sacramento River.

Analyses of 2007-2011 adult green sturgeon acoustic telemetry data does not indicate holding or potential spawning areas, defined as extended use of specific habitat, below Gianella Bridge (RK 320.6; M. Thomas, UCD, pers. comm.). Future egg sampling in the GCID area should seek to confirm this indirect data and identify if spawning can be detected below Gianella Bridge (RK 320.6).

Schafter (1997) detected spawning of white sturgeon *Acipenser transmontanus*, between RK 222.9 and RK 251.2 of the Sacramento River with movements of radio-tagged fish as high as RK 293. Vogel (2008) sampled adult sturgeon for a telemetry study near GCID between 2003 and 2006 and sampled white sturgeon as far as RK 264. Presently, it appears there is some overlap in spawn timing, but spatial overlap of spawning grounds appears doubtful between the two species (whites: Kohlhorst 1976, Schafter 1997; green: Poytress et al. 2009-2011). Determination of spawning habitat overlap or segregation between the two species may discern important habitat related variables or niches in the Sacramento River and should be pursued to better understand the habitat needs and basic life history attributes that separate these two species.

***Spawning substrate surveys*.—** UVC surveys conducted at RK 338 showed large deposits of sand within the backwater eddies on either side of the pool and on the downstream edge of the pool (RR9-13; MC9-16; RL4-10; Figure 9). Substrate similar to spawning micro-habitat described by Poytress et al. (2009-2011) was located in a small area between waypoints MC16-20 (Figure 9). High water velocity in this area assumedly prevents the buildup of sand leaving clean, small to medium sized gravel. Egg sampling at RK 338 didn't detect any eggs, however there was a limited number of samples collected from this micro-habitat between waypoints MC 16-20 (Figure 7). Mats were primarily placed downstream onto sandy substrates and were either partially or completely buried with sand in most samples, likely hindering their ability to collect eggs. Moreover, no adult green sturgeons were observed at this site breaching, by mobile acoustic telemetry receivers, or by sonar equipment.

RK 332.5 contained only surface turbulence (i.e., no standing waves) and was somewhat different than other spawning locations identified by Poytress et al. (2009-2011). Confirmed spawning areas such as RK 426, 424.5, 407.5, 377, and 366.5 have an armored (either naturally or man-made) upstream bank which funnels the river's flow producing high water velocities and vortices. As a result, large deep pools often with standing waves, backwater eddies, and a pool tail crest are formed. The river at RK 332.5 does not have a pronounced constriction point, >0.15 m standing waves and/or large turbulent vortices and resembles the habitat above the confluence of Deer Creek (RK 354). Egg mat surveys in 2009 did not document spawning activity at RK 354, an area known to hold small annual aggregations of green sturgeon. The 2009 survey results lead Poytress et al. (2010) to suggest the presence of standing waves may be one of several important characteristics of green sturgeon spawning habitat. However, the confirmation of spawning at RK 332.5 suggests the importance of standing waves may be limited or indirectly support green sturgeon spawning habitat.

Mat placement in 2011 was directed by acoustically tagged fish data and angler catch, not substrate surveys as they were performed post egg sampling. UVC surveys identified medium sized gravel substrate, suggested to be an important green sturgeon spawning habitat component (Poytress et al. 2010) throughout the survey area at RK 332.5 (RR6-23; MC1-16; Figure 10). Furthermore, egg sampling confirmed the use of this substrate by collecting a single egg near MC8 (Figure 10). Spawning presumably occurred upstream between waypoints RR7-23 or MC 8-16 (Figure 8). Based on substrate surveys, egg mat sampling primarily targeted the lower section of the potential spawning habitat at RK 332.5 and a large proportion of the area remained unsampled (Figure 8).

***Spatial and temporal distribution patterns of larvae*.—** The greatest total capture of green sturgeon larvae in four seasons of effort was achieved using a benthic D-net in 2011. A combined total of 643 green sturgeon larvae were sampled from the RBDD Bypass Outfall, Tehama Bridge, and Gianella Bridge (Table 4). Larvae had previously been collected at RBDD Bypass Outfall and Tehama Bridge in 2010 (Poytress et al. 2011). For the second consecutive year, larvae were sampled over a period of three months at two locations (Figure 11) over a distance of 22 river kilometers (Figure 1). Samples were collected at both locations beginning in May and ending in August. The first capture on May 23, 2011 at the RBDD Bypass Outfall (RK 391) occurred seven days later and was initiated as a result of larvae collections at the RBDD rotary traps (~500 meters upstream) on May 16,

2011. Egg sampling did not detect spawning activity at the 2011 sites until May 18, 2011 downstream of the D-net and rotary trap site. Eggs were not collected upstream of the larval capture sites until May 27, 2011. These data suggest that initial spawning events were not detected by our egg sampling efforts, but do appear consistent with the timing of spawning in April which has been documented consistently in the three prior years (Poytress et al. 2009-2011).

The temporal distribution pattern of green sturgeon larvae sampled in the benthic D-net resembles a nearly identical pattern exhibited by captures in the rotary traps at RBDD (Figure 11). Although fairly consistent with the RBDD Bypass Outfall sample site (located 500 meters downstream of the rotary traps at RBDD), the migration pattern is very consistent in trend and magnitude for the Tehama Bridge captures as well (Figure 11). Interestingly, both sample gears sampled larvae for two distinct periods (mid-May to mid-June and July through late-August) with a sixteen day period of no captures by either gear. These data suggest that two distinct spawning events (early and late season) may be occurring and spawning may be driven by environmental variables such as flow, temperature, moon phase, or day/night length.

In light of regulatory agency concerns pertaining to the impacts of sampling on early life stage green sturgeon, it would appear reasonable to discontinue D-net larval sampling in future years to determine annual emergence timing. The 2009-2011 data has consistently demonstrated that rotary traps sampling for Chinook salmon at RBDD are a reliable and appropriate source for this data. Future D-net sampling activities should focus exclusively on locations upstream of known spawning areas (e.g., Jelly's Ferry Bridge, Ball's Ferry Bridge or Bonnyview Bridge), with the goal of determining whether additional upstream habitat is currently being utilized by adults and supporting successful recruitment. Additional emphasis of D-net sampling should focus effort further downstream to determine the spatial extent of the first redistribution of larvae from hatching grounds as was done at Gianella Bridge in 2011. The mid-season addition of this sample site successfully determined that late season larvae migrated below the GCID diversion beginning and ending at a similar time to the late season catch of larvae in RBDD rotary traps (Figure 11).

***Nocturnal distribution patterns*.—** Laboratory observations of increased larval green sturgeon activity during the night time period (Van Eenennaam et al. 2001; Kynard et al. 2005), coupled with documented 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) were the primary drivers for our nocturnal benthic sampling efforts. Although standard D-net sampling occurred primarily between the hours of 20:00 and 01:00 each night, the protocol planned for sampling to cease one hour after the last green sturgeon capture. Permitted take restrictions issued by CDFG and NOAA Fisheries, under the 4(d) permit rules for take of green sturgeon, limited sampling effort by one night per week as exceedance of take levels appeared imminent. The first night of sampling in 2011 resulted in the capture of 45 larvae; compared to 62 individuals in the entire 2010 sample season. Sampling efforts concluded by 02:00 each night during 2011, eliminating our ability to obtain complete nocturnal distribution data on what appeared to be a second peak of activity as detected by Poytress et al. (2011). The aforementioned permit restrictions curtailed data collection and limited our ability to analyze nocturnal distribution patterns of green sturgeon larvae.

***Sample comparison of targeted and non-targeted larval surveys*.—** Green sturgeon larval samples collected by D-net at three 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.

Larval green sturgeon catch during the 2011 season was the highest on record for D-netting (*N* = 643) from the last four years and rotary trapping (*N* = 3,700) from the last 16 years. Green sturgeon relative abundance estimates for rotary trapping (catch per unit volume; Gaines and Martin 2002) and D-netting (catch per unit effort; Hubert 1996), which have typically been low for both methods, were much higher in 2011 than all previous years. Comparing the last four years where both methods were employed simultaneously revealed a strong trend in relative abundance values and a substantially greater index of abundance for 2011 (Figure 12). Although a number of variables contribute to relative abundance measures (e.g., catchability), it is hypothesized that 2011 being the first 'wet' year following multiple 'below normal' water years (according to the California Department of Water Resource's Sacramento River Water Year Index http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST), contributed greatly to the production of larvae detected by the two gear types in the upper Sacramento River. Additionally, for the rotary trap data, catchability may have been greater in 2011 than other years as spawning was confirmed, via egg mat sampling, to have occurred directly upstream of the east margin trap.

Rotary trap data from 2011 revealed two distinct patterns of abundance. The initial migration of larvae was detected by the full array of four traps across the river transect. The second, or late season, migration was sampled almost exclusively by a single trap placed in the east margin immediately downstream of where the single egg was sampled at RBDD in 2011. It would appear reasonable to assume the second migration was made up of the hatchlings from the RBDD spawning site. Following this assumption coupled with the estimated spawn date of the egg sampled immediately upstream of the trap (June 26, 2011), the data indicates dispersal from the hatching area begins within 18 days of egg deposition with a peak in dispersion at approximately 23-24 days. The dispersal period indicated by rotary trap data suggests initial dispersion from hatching areas is complete within 35 days of deposition.

Corresponding total length data for all sites exhibited the same pattern as in 2010 with a median size of 27 mm for all sites (Table 4). These data further the assumption that larvae are redistributing from hatching areas and not actively moving downstream long distances to feeding or rearing areas. These data suggest newly emerged green sturgeon larvae have the required food resources within the upper river during the late summer and fall. Moreover, the abrupt cessation of larval movement as determined by downstream sampling techniques such as passive D-nets and rotary traps suggest these fish may be moving upstream to forage for a period of time as noted in Kynard et al. (2005) after the initial dispersion. As noted in Poytress et al. (2011), it is likely that our sampling efforts do not capture a true downstream migration to juvenile rearing and overwintering areas, as was suggested by Kynard et al.

(2005). Directed sampling effort using D-nets should be discontinued in 2012 during the initial dispersal period provided rotary traps are in operation, as they provide adequate temporal distribution and hatching success data. Future D-net effort should be focused more so in the fall as water temperatures decrease below 10°C and fish reach the 180 day post hatch period as noted by Kynard et al. (2005) where it was hypothesized that juvenile green sturgeon migrate to overwintering areas. These efforts could provide the next portion of life history information which is currently lacking for SDPS green sturgeon.

Impacts of research and monitoring.— Of considerable concern, particularly amongst regulating and permitting entities, is the issue of take and incidental mortality of Threatened SDPS green sturgeon. As noted in NOAA's *Sturgeon Research Protocols for Shortnose, Atlantic, Gulf and Green Sturgeons* (Kahn and Mohead 2010), sampling the 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 2011 data collected by the USFWS revealed several notable differences in the mortality of individuals sampled by D-nets and rotary traps. For instance total mortality associated with D-net sampling was 17%, including those individuals that were sampled and found to be in poor physical condition (i.e., later sacrificed). This total mortality value was highly skewed as a result of the RBDD Bypass Outfall site which accounted for 45% of the 2011 mortality, yet only 25% of the 2011 catch (Table 5). By comparison, the Tehama Bridge site accounted for 55% of the 2011 mortality, yet 75% of the 2011 catch (Table 5). The considerable difference in mortality rates between these sample sites is presumably attributed to the rougher conditions larvae experienced in sample gear when sampled in the higher water velocities present at RBDD (Table 4). On average, the velocities at RBDD were 44% greater than at Tehama Bridge and 216% greater than at Gianella Bridge (Table 4) which had the lowest mortality rate of only 4% of the total catch.

Incidental mortality values related to USFWS RBDD rotary trapping over 15 years have historically been highly variable, ranging from 0.74% to 54.1% ($\bar{x}$ = 18.3%) annually. The mortality rate for 2011 rotary trap sampling was 21.4% (Table 5). Sample effort was reduced and additional shifts were added, coupled with supplementary custom built sturgeon refuges to maintain an acceptable level of mortality. The ability to successfully sample fragile age-0 larvae allowed the USFWS to transfer 60 live green sturgeon to the USBR, (Table 5) for use in additional research to be conducted by UCD (NMFS 2009). Furthermore, incidental mortality specimens from rotary trapping (N = 790) and D-net sampling (N = 110) were provided to UCD for genetics testing (Israel et al. 2004) and for kinship reconstruction and estimating breeding population size (Israel and May 2010) as required under the NMFS OCAP BO RBDD mitigation reasonable and prudent measures (NMFS 2009).

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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 five 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	4/12/11	7/18/11	4	291.0	9	0.031
Massacre Flats (RK 424.5)	Pool	4/12/11	7/18/11	4	282.8	-	0.000
RBDD (RK 391)	Dam[a]	6/26/11	7/29/11	4	119.6	1	0.008
Lone Oak (RK 338)	Pool	4/12/11	7/15/11	4	240.6	-	0.000
GCID Hole (RK 332.5)	Pool/Glide	4/12/11	7/15/11	4	309.4	1	0.003
			Total	**20**	**1,243.4**	**11**	**0.043**

[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 on the upper Sacramento River, CA. Estimated spawn date and estimated hours post fertilization 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**	**Est. Hrs post Fertil.**	**Stage**	**Comments**
5/18/11	RK 332.5	1	5/15/11	60	21	Early neurulation
5/27/11	RK 426	1	5/24/11	-	-	Fungused egg; fertilization indeterminate
5/27/11	RK 426	1	5/24/11	-	-	Not viable, appeared fertilized, died.
6/13/11	RK 426	1	6/10/11	-	-	Not viable, appeared fertilized, died.
6/13/11	RK 426	1	6/10/11	-	-	Not viable, fertilization indeterminate
6/13/11	RK 426	1	6/10/11	60	21	Early neurulation
6/13/11	RK 426	1	6/10/11	60	21	Egg partially burst in EtOH. Early nearulation.
6/20/11	RK 426	1	6/14/11	144	35	Post hatch larvae; total length 13.2 mm
6/20/11	RK 426	1	6/14/11	144	35	Post hatch larvae
6/20/11	RK 426	1	6/14/11	144	35	Post hatch larvae
6/29/11	RK 391	1	6/26/11	60	21	Early neurulation
	Total	**11**				

Table 3. Summary of egg mat sample depths and green sturgeon egg sample depths recorded during the 2011 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	1.3	6.4	12.5	7.7	9.3	11.1
Massacre Flats (RK 424.5)	Pool	2.7	6.7	14.5	-	-	-
RBDD (RK 391)	Dam[a]	0.7	1.6	3.6	-	2.0	-
Lone Oak (RK 338)	Pool	3.5	7.3	11.6	-	-	-
GCID Hole (RK 332.5)	Pool/Glide	3.6	6.4	9.9	-	7.1	-

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

Table 4. Benthic D-net sample effort, green sturgeon (GST) catch, catch per unit effort (CPUE), median total length (TL), net depth and water velocity for samples containing green sturgeon larval during 2011 on the Sacramento River, CA.

						Depth (m)			Velocity (m/sec)		
Sample Type	**Sample Site**	**Effort (min)**	**GST Catch**	**CPUE**	**TL (mm)**	**Min**	**Ave**	**Max**	**Min**	**Ave**	**Max**
Standard	RBDD Bypass Outfall (RK 391)	8,393	119	0.014	27	1.5	1.7	2.1	0.8	1.3	1.4
Standard	Tehama Bridge (RK 369)	9,472	477	0.050	27	1.6	1.9	2.8	0.8	1.0	1.1
Exploratory [a]	Gianella Bridge (RK 320.6)	2,139	47	0.022	27	1.3	1.5	1.6	0.4	0.6	0.6
	Total	**20,004**	**643**	**0.086**							

[a] Exploratory sample site initiated mid-season due to 2011 4(d) permit green sturgeon take restrictions imposed by CDFG and NOAA Fisheries.

Table 5. Disposition of 2011 green sturgeon larvae sampled by benthic D-net and rotary traps on the upper Sacramento River, CA.

			Mortality			Live	
Sample Gear	**Sample Site**	**Total**	**Direct**	**Sacrifice[a]**	**% Mort**	**Transfer[b]**	**Release**
Benthic D-net	RBDD Bypass Outfall (RK 391)	119	42	8	42.0	-	69
Rotary Trap	RBDD (RK 391)	3,700	790	-	21.4	55	2,855
Benthic D-net	Tehama Bridge (RK 369)	477	49	9	12.2	5	414
Benthic D-net	Gianella Bridge (RK 320.6)	47	2	-	4.3	-	45

[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

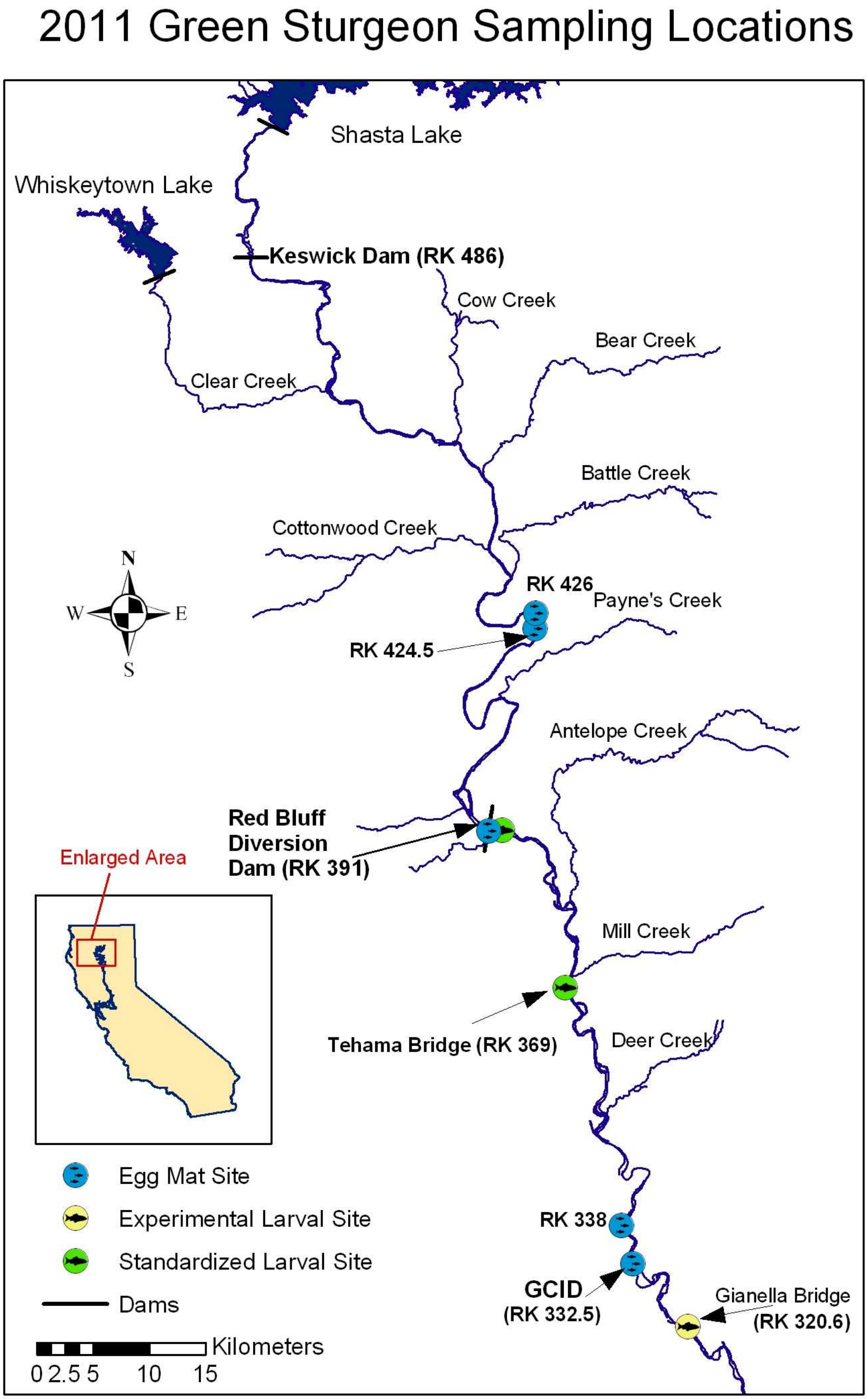

Figure 1. Green sturgeon egg and larval sample sites on the upper Sacramento River, CA.

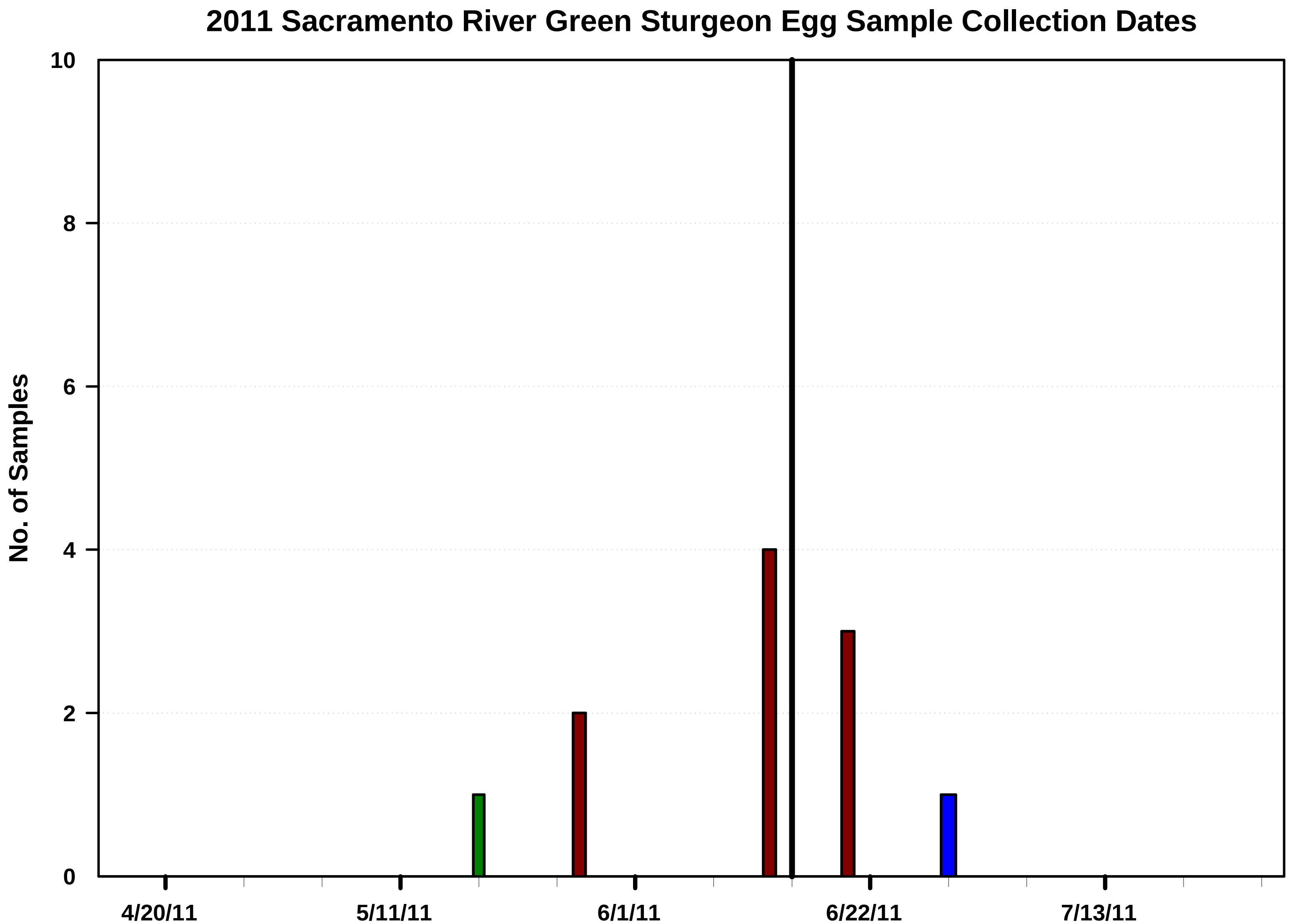

Figure 2. Temporal distribution of green sturgeon egg samples collected at Ink's Creek (RK 426; red bars), RBDD (RK 391; blue bar), and GCID (RK 332.5; green bar) on the Sacramento River, CA. Black vertical line indicates RBDD gate closure on June 15, 2011.

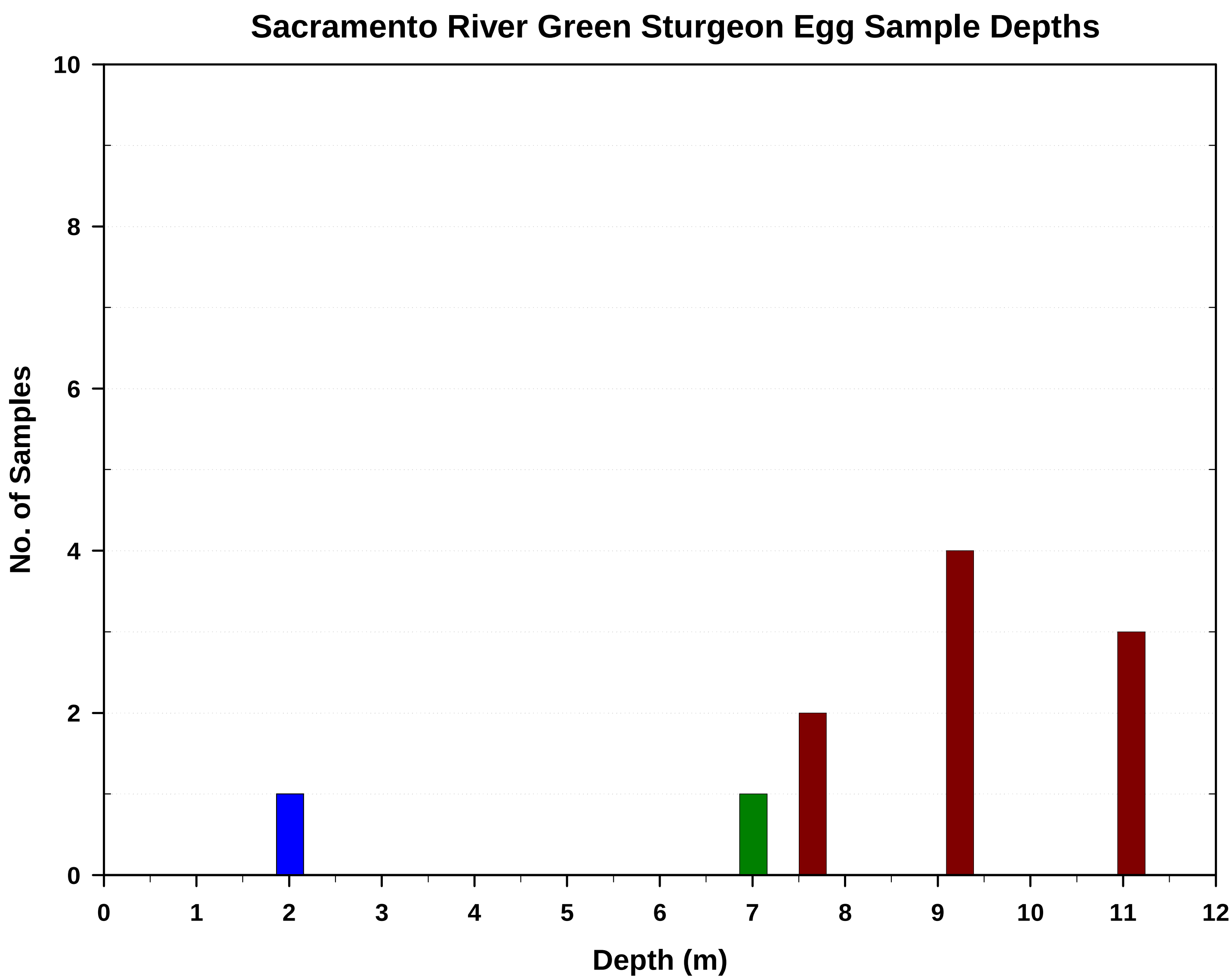

Figure 3. River depths of green sturgeon eggs sampled from egg mats at Ink's Creek (RK 426; red bars), RBDD (RK 391; blue bar), and GCID Hole (RK 332.5; green bar) on the Sacramento River, CA for the period May 18 - June 29, 2011.

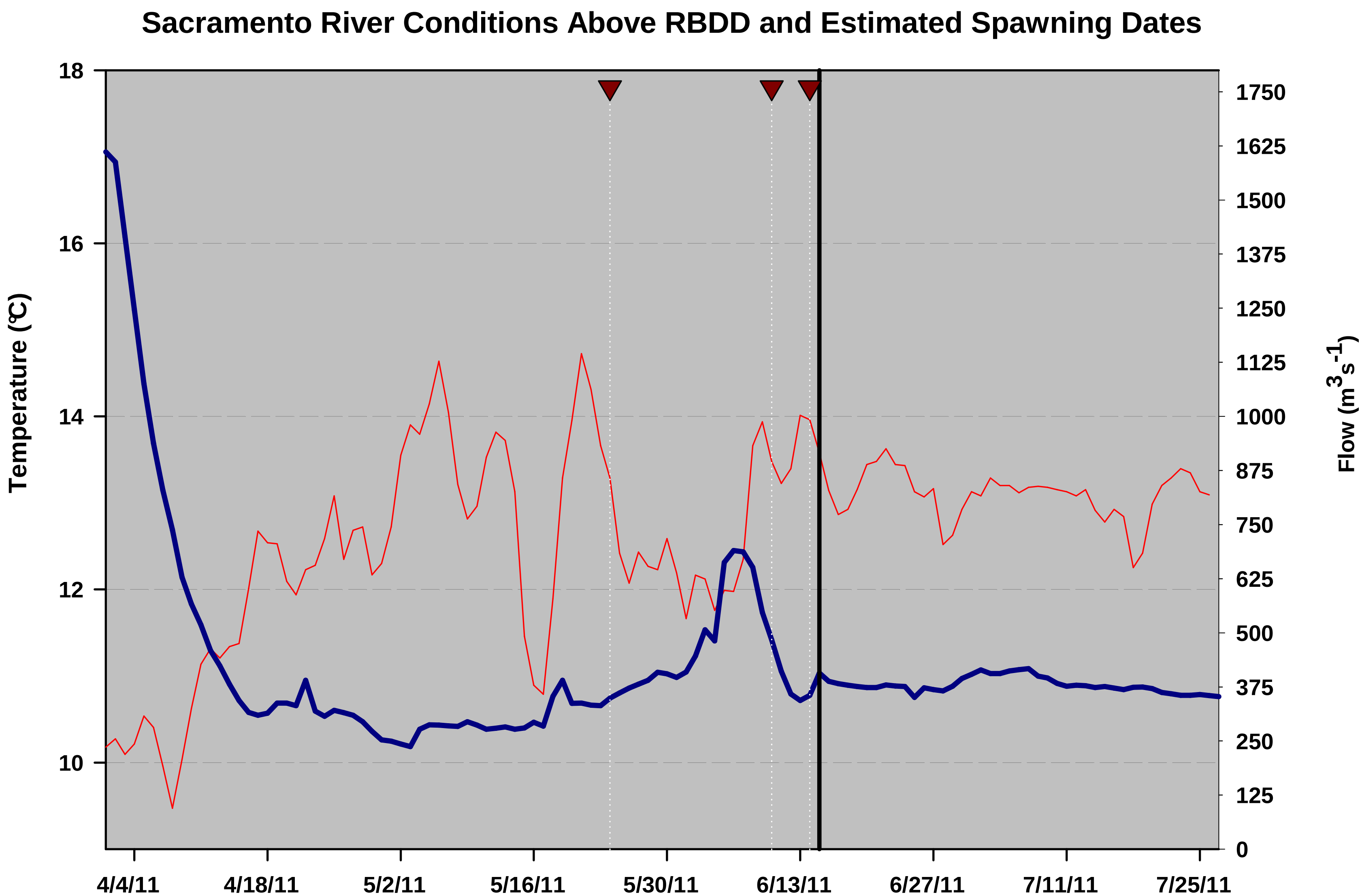

Figure 4. Sacramento River mean daily flow (dark blue) and mean daily temperature (red) at Bend Bridge gauging station. Inverted triangles indicate estimated spawning dates for Ink's Creek (RK 426; red). Black vertical line indicates RBDD gate closure on June 15, 2011.

Sacramento River Conditions Below RBDD and Estimated Spawning Date

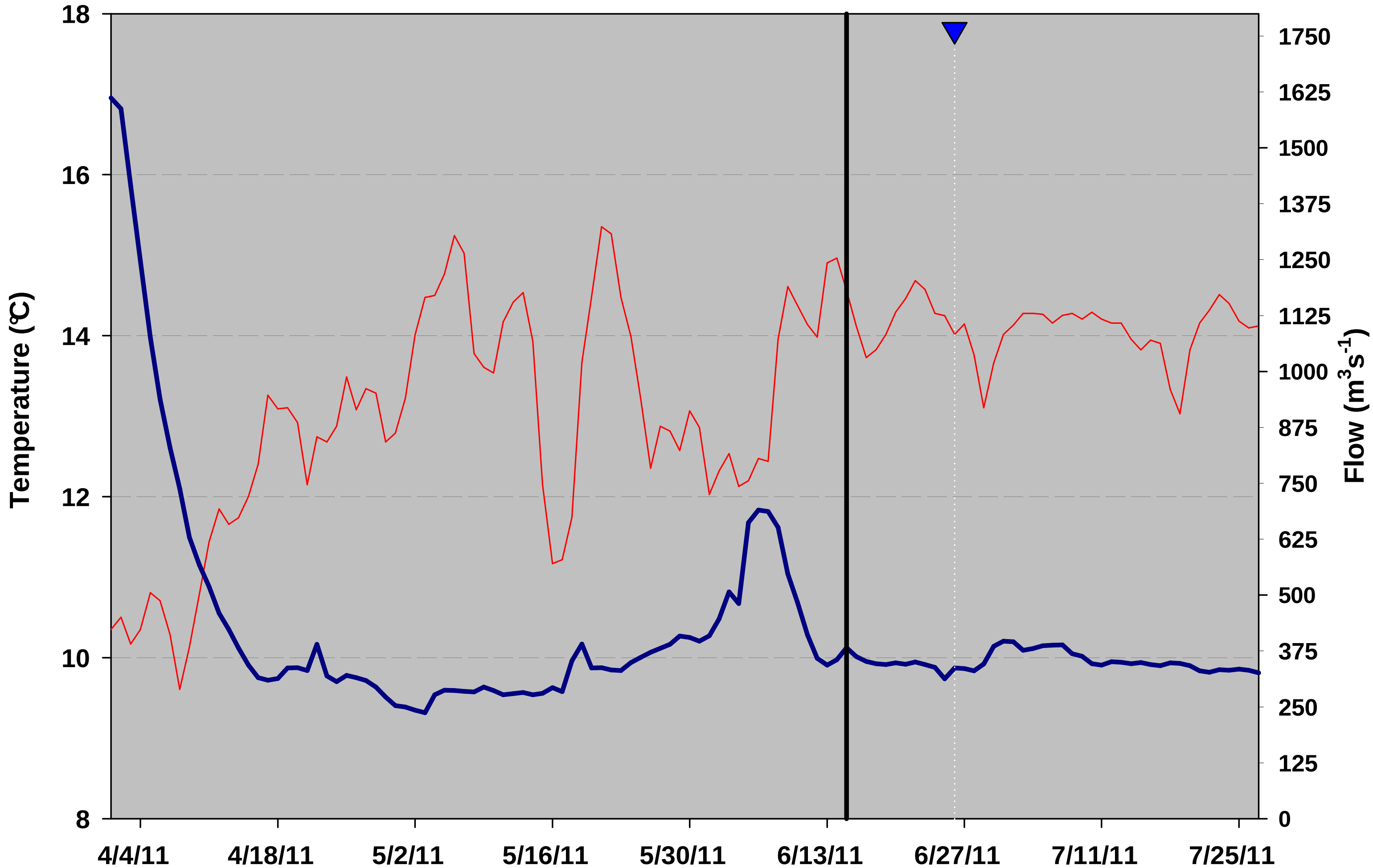

Figure 5. Sacramento River mean daily flow (dark blue) and mean daily temperature (red) at Bend Bridge gauging station minus RBDD diversions (when applicable). Inverted triangles indicate estimated spawning dates for RBDD (RK 391; blue). Black vertical line indicates RBDD gate closure on June 15, 2011.

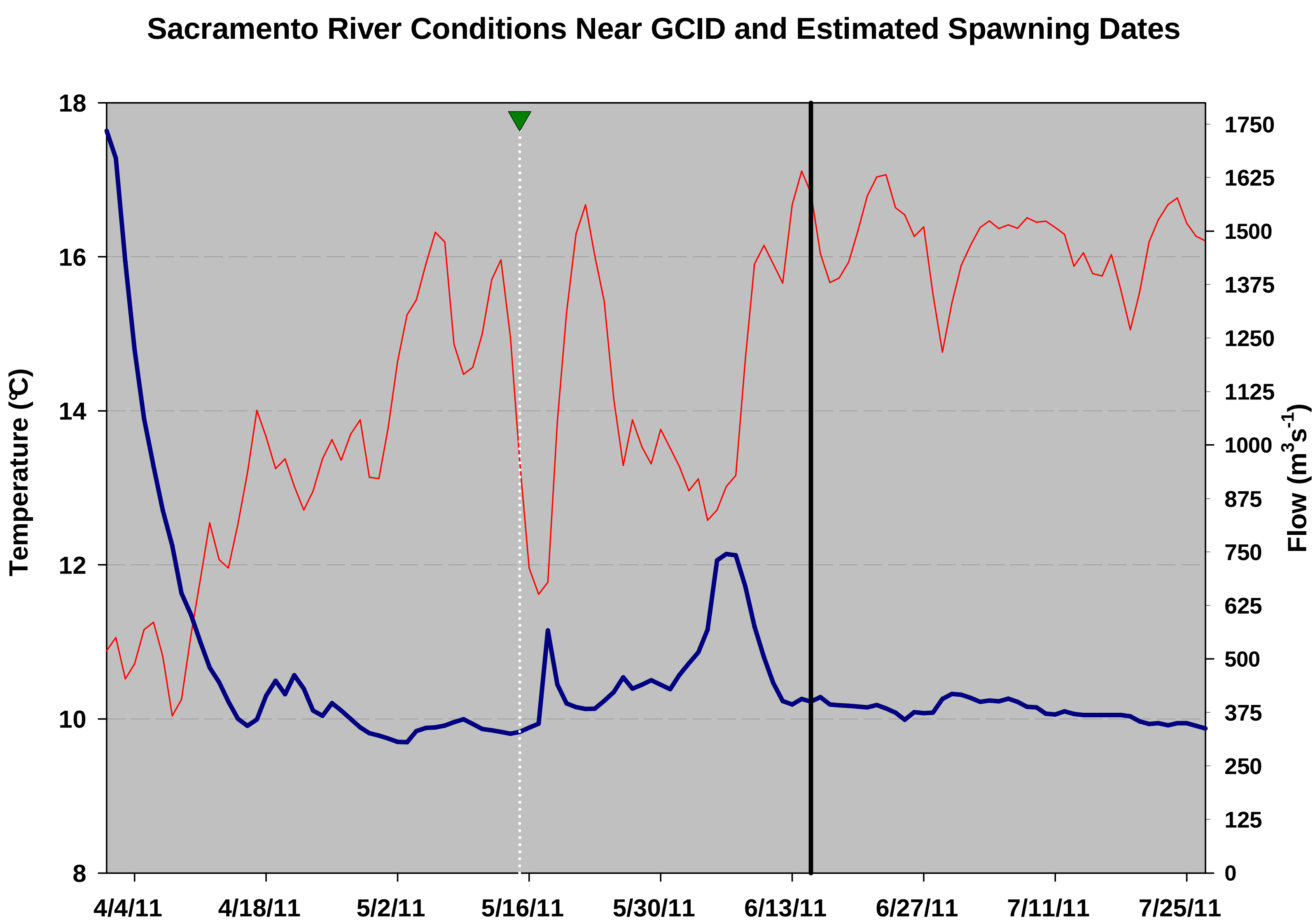

Figure 6. Sacramento River mean daily flow (dark blue) and mean daily temperature (red) at Vina-Woodson Bridge gauging station. Inverted triangles indicate estimated spawning dates for GCID Hole (RK 332.5; green). Black vertical line indicates RBDD gate closure on June 15, 2011.

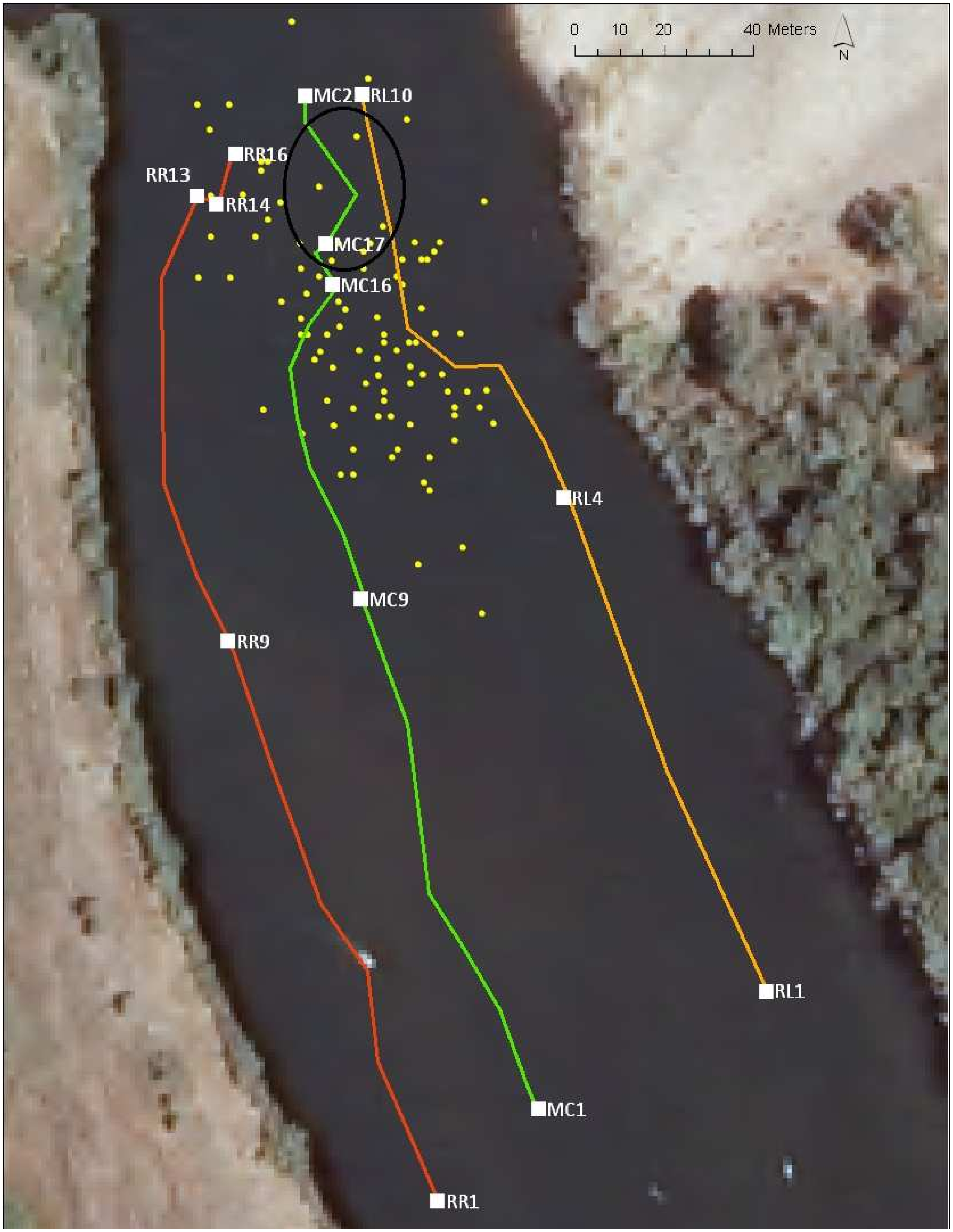

Figure 7. Underwater video tracks and egg mat sampling locations (yellow dots) at Lone Oak (RK 338). White squares represent the location of underwater video snapshots (Figure 9). Black circle indicates area of small to medium gravel substrate.

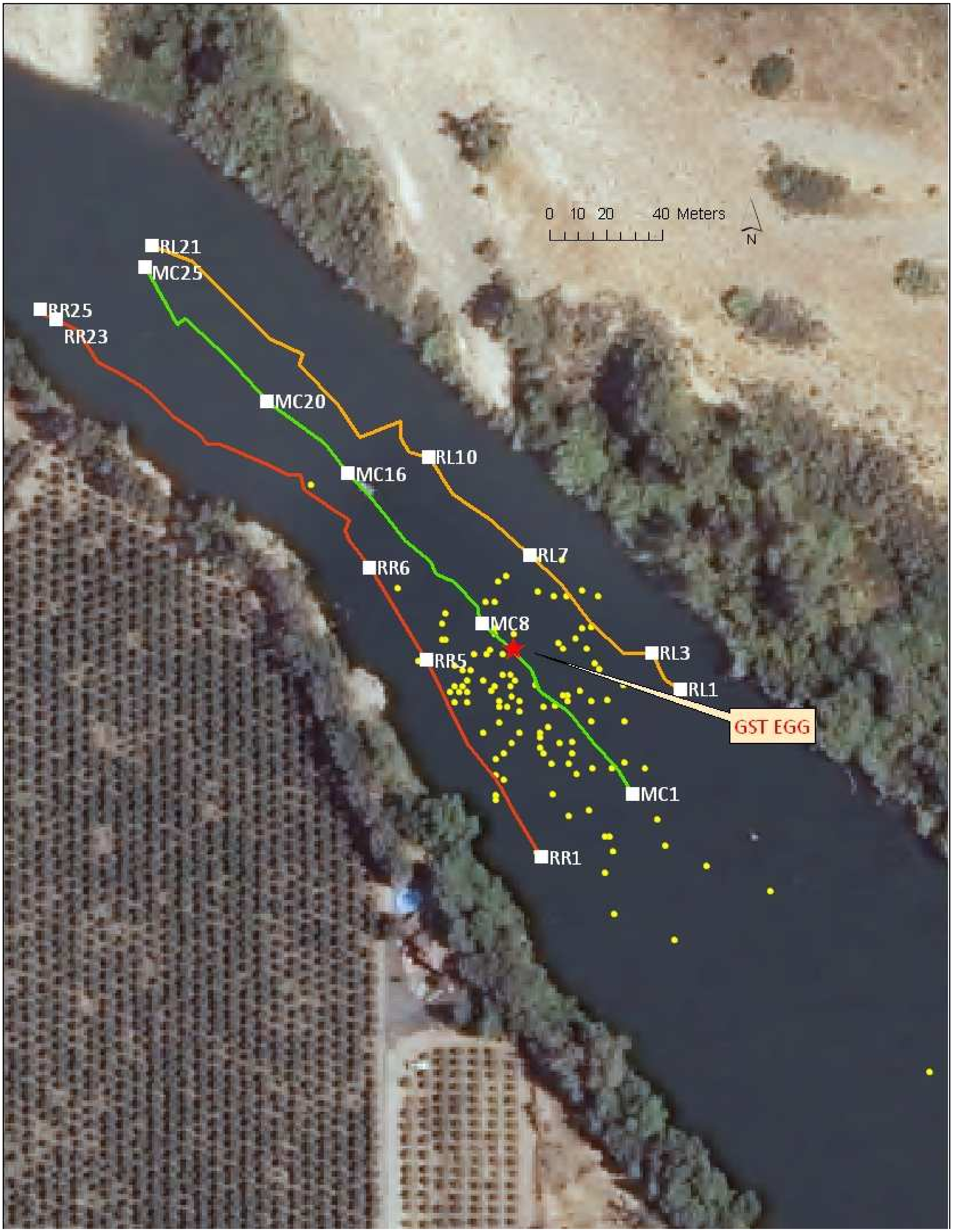

Figure 8. Underwater video tracks and egg mat sampling locations (yellow dots) at GCID Hole (RK332.5). White squares represent the location of underwater video snapshots (Figure 10). Red star denotes the location of the green sturgeon egg sampled on May 18, 2011.

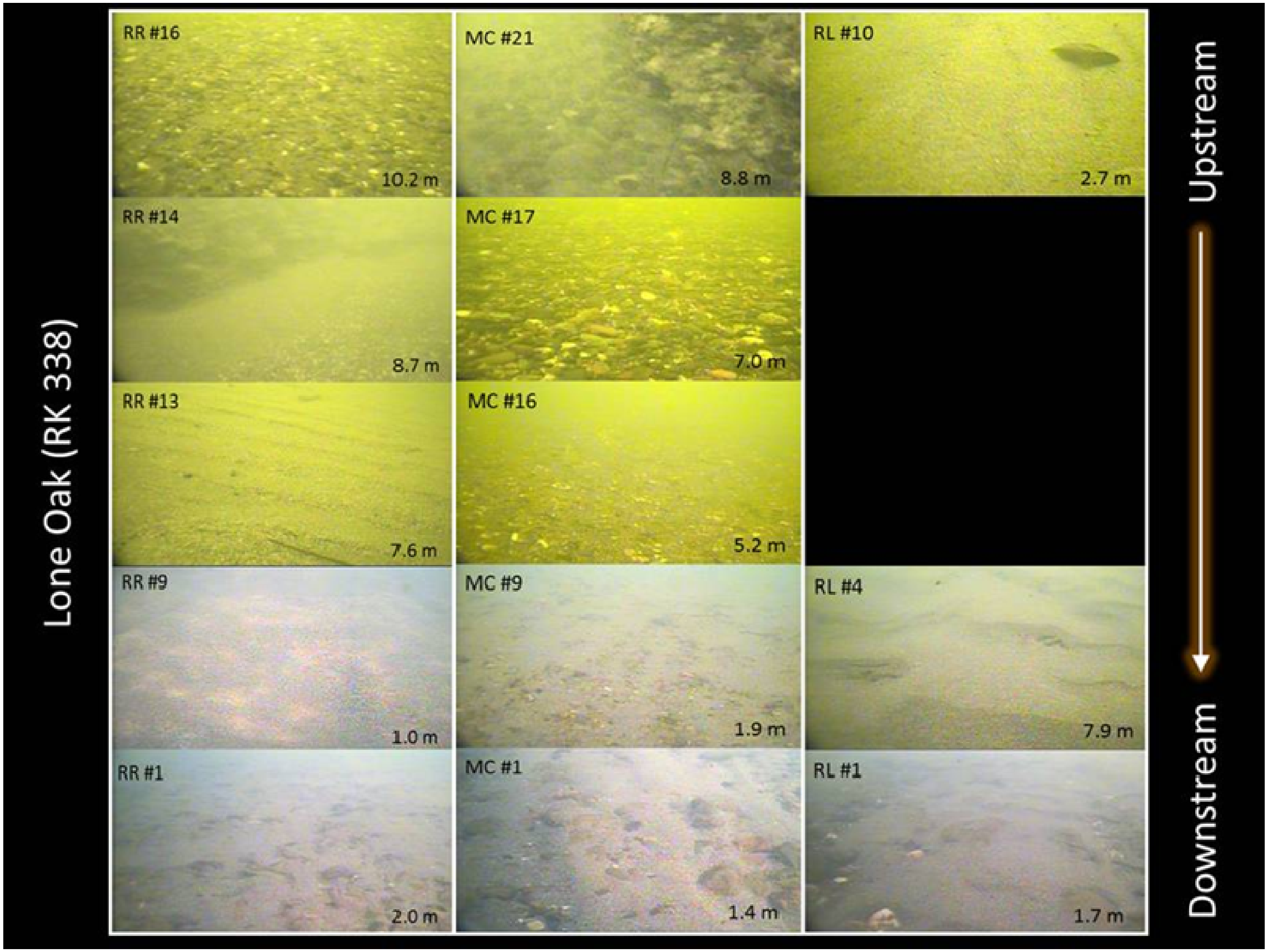

Figure 9. Underwater video camera snapshots of substrate at Lone Oak (RK 338).

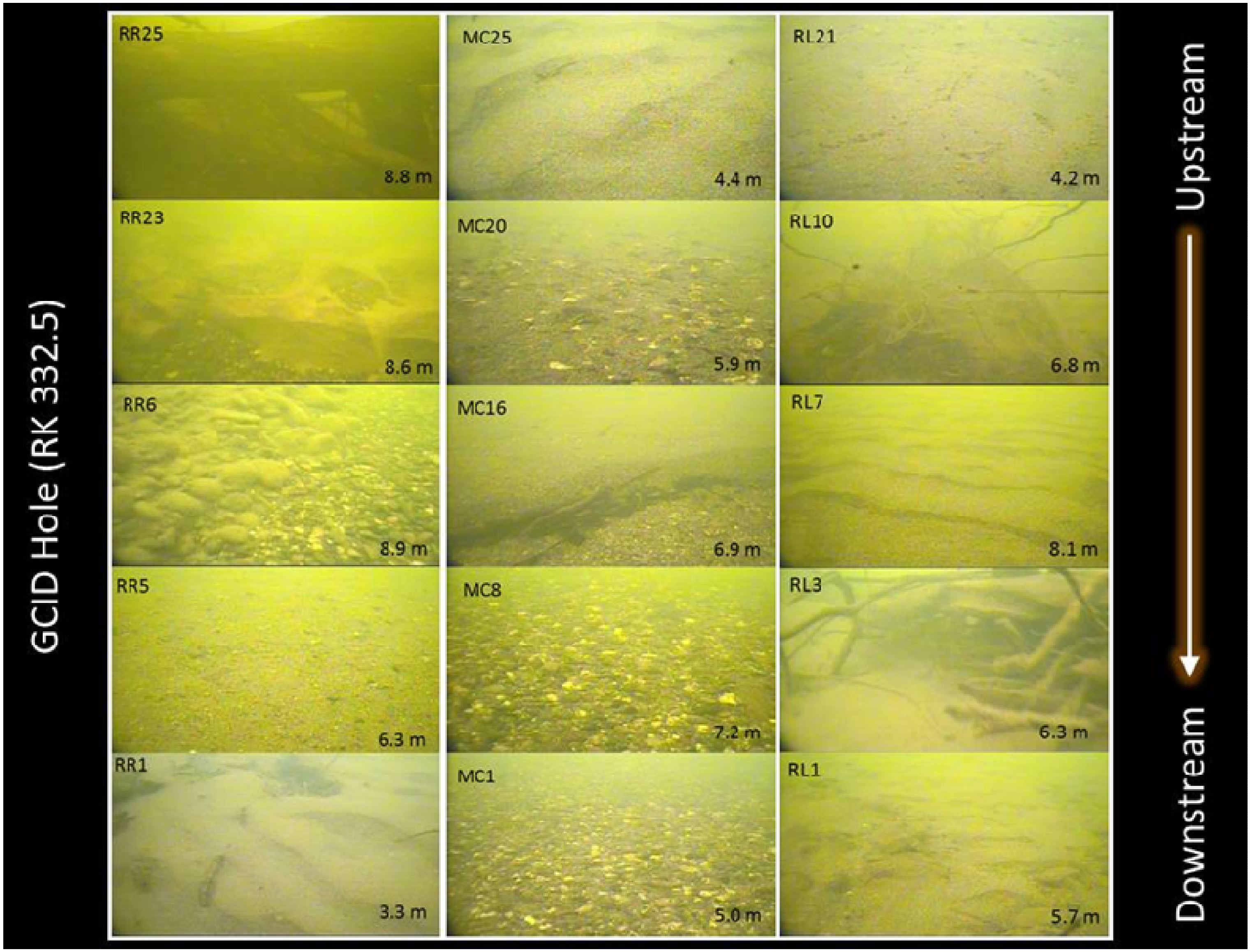

Figure 10. Underwater video camera snapshots of substrate at GCID Hole (RK 332.5).

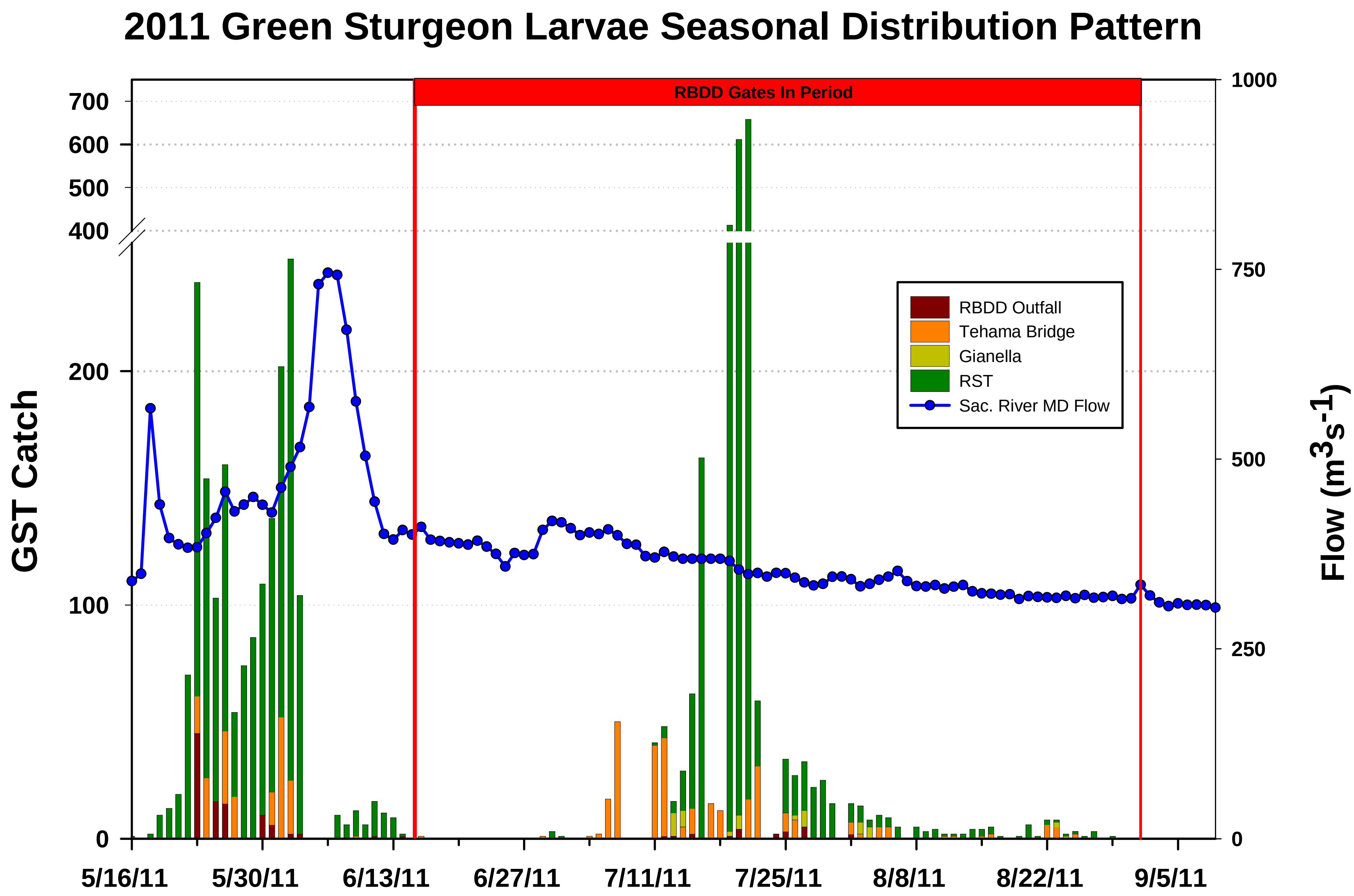

Figure 11. Green sturgeon larvae catch distribution pattern. Rotary trap sampling was conducted throughout 2011 and green sturgeon were caught between May 16 through August 29. D-net sampling occurred from May 23 through September 9 at the RBDD Bypass Outfall (RK 391) and Tehama Bridge (RK 369). Sampling was conducted beginning July 13 at Gianella Bridge (RK 320.6) one night per week as a result of 4 (d) permit restrictions.

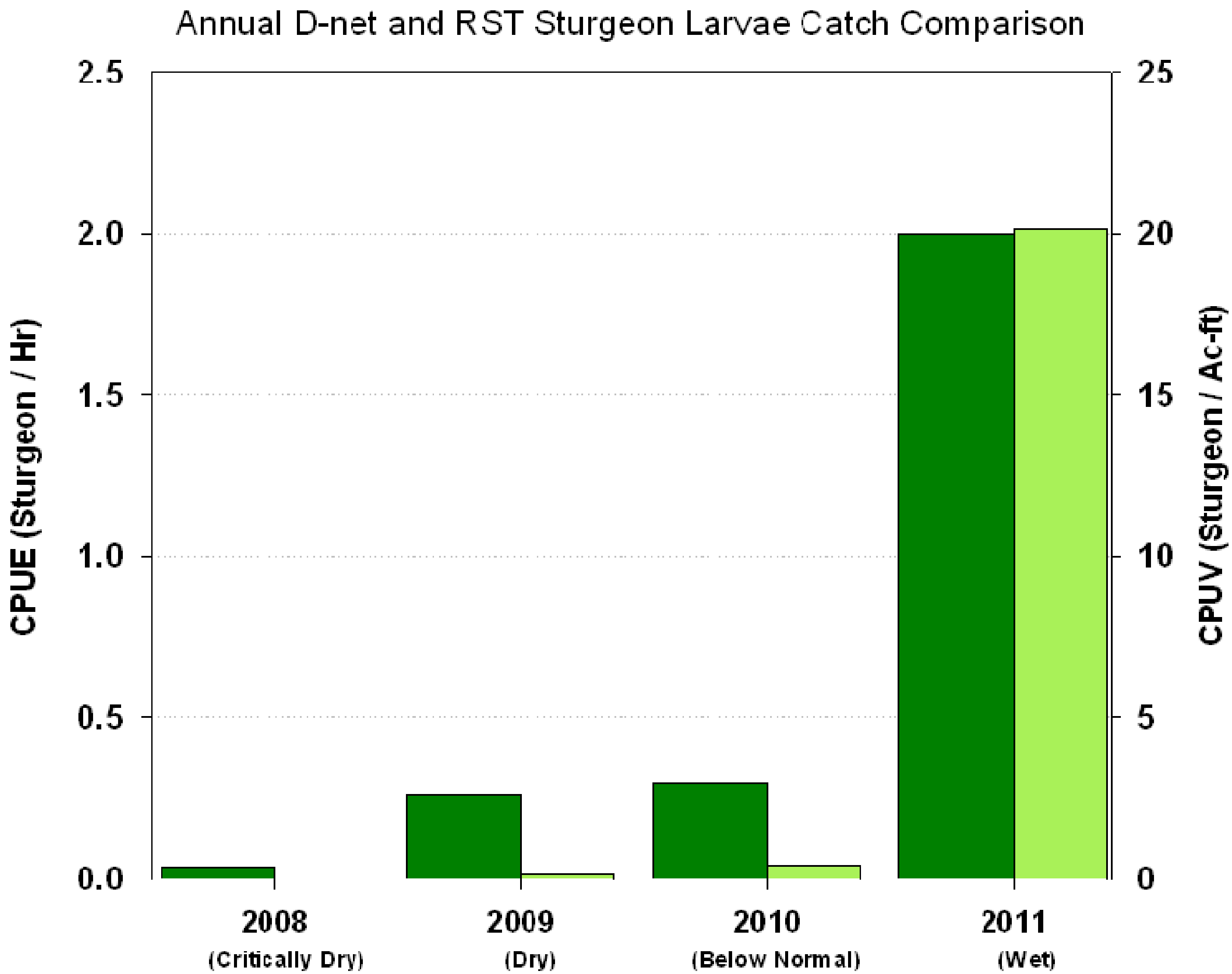

Figure 12. Comparison of D-net catch per unit effort (sturgeon/hr) and rotary trap catch per unit volume (sturgeon/acre-foot) for the period of May through August 2008-2011. No sturgeon were sampled by rotary traps in 2008. Sacramento River Valley Water Year Index in parenthesis.