

**2009 UPPER SACRAMENTO RIVER GREEN STURGEON SPAWNING HABITAT
AND LARVAL MIGRATION SURVEYS**

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Cover Photo: Two green sturgeon eggs adhered to each other sampled on June 5, 2009 using artificial substrate mats in the Sacramento River, CA. Eggs were determined to be in the late cleavage stage (Stage 10) using Detlaff et al 1993. Photo courtesy of UC Davis using a Nikon DS-U1 digital camera connected to a microscope.

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2009 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys

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Abstract.— Four spawning sites of Southern Distinct Population Segment green sturgeon, *Acipenser medirostris*, were confirmed in the upper Sacramento River, California in 2009. Three confirmed sites from 2008 surveys were reconfirmed and one of three newly sampled sites in 2009 was confirmed. Fifty-six positively identified green sturgeon eggs were sampled by artificial substrate mats with placement guided by 2008 and 2009 acoustic telemetry data and limited underwater video of substrate. Two of three new egg sample sites had substrates surveyed (RK 407.5 and RK 354/353) using underwater videography. Spawning events occurred several river kilometers upstream and downstream of the Red Bluff Diversion Dam (RBDD) prior to, and subsequent to, the June 15 seasonal dam gate closure. Spawning occurred directly below RBDD within two weeks after the gate closure. The temporal distribution pattern suggested by this second year of study indicates spawning of Sacramento River green sturgeon occurs from early April through late June. Sample depths for eggs collected from all of the sites combined ranged from 0.8 to 9.4 m (\bar{x} = 4.7 m). Overall, green sturgeon eggs sampled from the RBDD sample site were found in depths ranging from 1.0 to 7.9 m (\bar{x} = 4.9 m) *less* than the other three sites. Sacramento River flows and temperatures for the *above* RBDD sites ranged from 156 to 460 m³s⁻¹ (\bar{x} = 250 m³s⁻¹) and 10.8 to 14.2°C (\bar{x} = 12.7°C) during the estimated spawning period. Sacramento River flows and temperatures for the *below* RBDD sites ranged from 210 to 460 m³s⁻¹ (\bar{x} = 289 m³s⁻¹) and 11.2 to 16.0°C (\bar{x} = 14.5°C) during the estimated spawning period.

Sampling for drifting larvae using a benthic D-net proved successful, albeit the season was plagued with mechanical failures. Forty-five green sturgeons were sampled between June 9 and July 17. Sixteen larvae were sampled on a single night from one of two all night experimental larval sampling surveys conducted within confirmed green sturgeon spawning habitat. Some nocturnal distribution data was derived from the all night sampling effort. All larvae were sampled from the solitary mid-channel habitat indicating a possible preference for mid-channel environments or swift water velocity areas. Fyke nets concurrently deployed during all night experimental larval sampling surveys collected migrating green sturgeon larvae in the mid-channel environment on one of two occasions. These data gave further credence to the mid-channel habitat use theory. Two sample sites upstream of the RBDD resulted in a catch of zero green sturgeon larvae, yet one site had sampling severely limited by noise concerns of local residents. Increased, sustained sampling effort focusing on various mid-channel environments needs to be conducted to better define the drift characteristics of larval green sturgeon.

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2009 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys

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. In 2008 and 2009, the USBR and the University of California, Davis (UCD) conducted research and monitoring on the adult life history phase of 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 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.

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

Objectives

The objectives of this second-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 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) determine if alternate means could be used to sample migrating green sturgeon larvae by employing experimental gear concurrently with standard gear types.

This annual report addresses, in detail, egg and larval sampling of green sturgeon for the period March 30 through July 31, 2009. This report includes data and information on

green sturgeon spawning areas, larval drift characteristics, and limited qualitative spawning substrate surveys from multiple upper Sacramento River sites centered on the RBDD. This report will be 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 (RK 485), have formed a complete barrier to upstream anadromous fish passage since 1943 (Moffett 1949). The 94 river kilometer reach between Keswick Dam and RBDD (RK 391) supports areas of intact riparian vegetation and largely remains unobstructed. Below RBDD the river encounters increasingly greater anthropogenic influence until it drains into the Sacramento-San Joaquin Estuary.

Sampling was concentrated in a 77 river kilometer (RK) reach of the Sacramento River from Jelly's Ferry Bridge (RK 429) to Woodson Bridge (RK 352) with RBDD half way in between (Figure 1). The 2009 study area contained 3 confirmed spawning micro-habitats (Brown 2007, Poytress et al. 2009) and was expanded to sample 3 likely spawning micro-habitats associated with the presence of green sturgeon based on 2008 and 2009 acoustic telemetry data (M. Thomas, UCD and R. Corwin, USBR, 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 2009, as described, provided an increased number of logistically feasible sampling locations over that in 2008 both upstream and downstream of 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 (M. Thomas, UCD and R. Corwin, USBR, 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; Brown 2007, Poytress et al. 2009). 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 polyvinyl chloride (PVC) anchor attached to the upstream end of the egg mat using two 76 cm pieces of 6.4 mm diameter aircraft cable or 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 (Figure 2a). 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 Massacre Flats (RK 424.5), the Salmon Hole (RK 423), Turkey Beach (RK 407.5), below the mouth of Antelope Creek (RK 377), and above and below the mouth of Deer Creek (RK 354 and 353; 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 study (Poytress et al. 2009). Some new sites were sampled more intensely with mats placed in specific areas based on shipboard tracking of adults in 2008 (M. Thomas, UCD, unpublished data).

Two sets of paired egg mats were placed in the confirmed spawning area (Brown 2007, Poytress et al. 2009) directly below RBDD (RK 391) following the annual, seasonal gate lowering which occurred on June 15, 2009. Egg mats were deployed downstream of 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 was obtained from the California Data Exchange Center's Bend Bridge (<http://cdec.water.ca.gov/cgi-progs/queryF?BND>) and Vina-Woodson Bridge gauging stations (<http://cdec.water.ca.gov/cgi-progs/queryF?vin>). Sacramento River flows for the three sites above RBDD were estimated using Bend Bridge gauging station data. Flows below RBDD and for the mouth of Antelope Creek site were estimated by using Bend Bridge data subtracting daily diversions at RBDD (when applicable). River flow data for the Deer Creek area was estimated using the Vina-Woodson Bridge gauging station. Sample effort data consisted of the date and time egg samplers 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 (Figure 2b), 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 (Figure 2c). After a second egg mat inspection and inspection of the filtered rinse 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, 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 UC Davis for positive 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. Representative photographs were taken with a Nikon DS-U1 digital camera connected to the microscope.

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. Non-green sturgeon eggs were field identified using a draft egg key provided by Rene Reyes and Dr. Johnson Wang of the US Bureau of Reclamation's Tracy Fish Salvage Facility. All confirmed and potential green sturgeon eggs were sent to Dr. Josh Israel of UCD for genetic confirmation (Israel et al. 2004) and further analysis.

Spawning substrate surveys.— Qualitative substrate identification and composition surveys of green sturgeon deep water spawning habitat were performed in a limited capacity using underwater videography. Surveys were performed at new egg mat sampling sites as time and resources permitted. Egg sample sites surveyed in 2008 (RK 424.5, RK 377; Poytress et al. 2009) were not resurveyed in 2009. 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). Deep water habitat surveys were performed using a PC-221-HR color video camera contained within a fabricated PVC underwater housing attached to 30.5 m of video and power cable. 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 (Figure 3). 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 single or multiple transects, or passes, depending on channel width or total area of egg sampling sites. Each pass performed with the underwater video camera (UVC) typically proceeded longitudinally from the furthest point downstream to the upstream end of suspected sturgeon spawning areas, based on the presence of acoustically tagged adults. The UVC (facing upstream) was lowered in the water column, typically, near the pool tail crest until substrate was clearly visible on the LCD monitor. Surveys progressed slowly upstream (1- 2 km/hr) through the holding 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 longitudinal pass. Individual passes were further broken down into sections as GPS coordinates were taken where distinct substrate changes occurred. 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, 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. Photos, video segments, and GPS were used 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 through August based on suspected spawning and juvenile outmigration timing (Gaines and Martin 2002; Van Eenennaam et al. 2001; Brown 2007, Poytress et al. 2009). Successful egg capture during the concurrent USFWS egg mat sampling refined the exact start and end dates. Based on previous studies on the Sacramento River (Brown 2007; Poytress et al. 2009) 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 (Figure 4). 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 net weight of 27 kg was determined to be sufficient for proper sampling. The net was attached via a 4.8 mm diameter wire rope bridle to 2.4 mm cable and positioned using a 12 volt ATV winch. The net was allowed to drift downriver behind the boat until it set and held firmly on the river bottom.

Larval drift sampling was scheduled for five days per week between three sample sites (Figure 1); Jelly's Ferry Bridge (RK 429), Bend Bridge (RK 415), and RBDD Bypass Outfall (RK 391). Sites were selected for their proximity to suspected spawning locations over a 40 km stretch above and directly below RBDD, ease of accessibility at night, and the presence of adequate tie-off structures (e.g., bridge supports) in varied depths and velocities. The Bend Bridge abutments and RBDD Bypass Outfall were selected as sample sites based on previous larvae catch at Bend Bridge (Brown 2007) and historic catch in the RBDD rotary screw traps (Gaines and Martin 2002). Jelly's Ferry Bridge was selected as the next nearest upstream sampling location to meet the sampling criteria objectives. Sampling at RBDD occurred every other night and Bend Bridge and Jelly's Ferry Bridge were sampled jointly on the opposite nights.

Sampling effort was designed to generally consist of a total of 300 minutes of wetted net time per night between the hours of 20:00 to 02:00. During split site sampling, nightly effort was split into a 120 minute wetted net sample period at Bend Bridge from the hours of 20:00 to 22:00 and then one 180 minute period at Jelly's Ferry between the hours of 23:00

and 02:00. Concerns raised by local residents over winch noise precluded sampling at Bend Bridge beyond 22:00. Bridge supports at Jelly's Ferry Bridge and Bend Bridge allowed for two sampling locations (i.e., tie-offs) at each site, one towards river right and one towards river left. 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 20, 30, or 60 minute sets depending on debris accumulation and fish occurrence and mortality.

Effort and environmental data collected for each sample site included: set and retrieve times and dates, estimated tie-off distance, estimated net set distance, depth, turbidity, and river velocity. The river velocity was measured at the surface adjacent to the sampling vessel using a General Oceanic® Model 2030 flowmeter. D-net sample depth was measured by mounting an Onset Corporation® Depth Logger to the frame of the D-net. 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. Non-sturgeon eggs were identified using a draft egg identification key provided by Rene Reyes and Dr. Johnson Wang of the US 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.— In addition to the standardized sampling regime, experimental sampling was conducted to investigate alternate sampling gear strategies and to obtain nocturnal distribution data. Exploratory sampling occurred within or directly below confirmed spawning areas at 1) below the mouth of Antelope Creek (RK 377) and (2) Massacre Flats (RK 424.5). Exploratory sampling was comprised of continuous benthic D-net sampling throughout the period from sunset to sunrise while concurrently sampling the same period and general area with two 1.2 m X 1.2 m, 0.8 cm mesh fyke nets. Multiple samples were also collected with 11 m bag seines in suitable areas in close proximity to spawning sites. While conducting all night exploratory sampling, the benthic D-net was generally set to sample repeatedly for 20 to 30 minute sets depending on debris accumulation and fish occurrence. Sample effort and catch data for the benthic D-net sampling included all previously mentioned data as collected during standardized sampling. Fyke net sampling consisted of initial deployment at or near sunset with two sample/gear checks; one near midnight and one after dawn. Fyke and seine effort data consisted of deployment and sample times and GPS locations of sampling devices. Catch data was processed in a similar fashion to D-net derived data.

Results

Egg sampling surveys.— Egg mat sampling occurred between March 30 and July 31, 2009. RBDD mats were deployed on June 26, 2009, following the lowering of the dam gates on June 15, 2009, and sampled until July 31, 2009. Egg mats sampled a total of 2,057.4 wetted mat days (wmd; one mat set 24 hours; Table 1). Sampling effort between the 6 sites ranged from 147.4 to 603.3 wmd (\bar{x} = 342.9; Table 1). Five mats were lost over the course of the sampling season. Three were lost in the high velocity, hydraulically active area of Turkey Beach (RK 407.5). On May 1, 2009 all sites' mats were retrieved due to a storm/flow event and redeployed four to seven days later. On July 30 above RBDD and July 31, 2009 RBDD and below mats ceased sampling and were removed from the river.

Between April 2 and July 1, 2009 fifty-six eggs were sampled by egg mats and positively identified as green sturgeon eggs (Figure 5). Positively identified egg samples were collected at RK 424.5 (N = 9), RK 407.5 (N = 2), RK 391 (N = 2), and RK 377 (N = 43). Egg samples were collected on 18 different sample days. On 8 occasions eggs were sampled from two different mats within the same site and on one occasion eggs were sampled from three different mats within the same site. Green sturgeon eggs were found adhered to the top (N = 30) and bottom (N = 26) of the egg mats. On five occasions eggs were found on both sides of the same egg mat. During one mat sampling event, two eggs were found adhered together along with sand particles (See cover photo).

Catch per unit effort (sturgeon eggs/wmd) ranged from 0.000 at the Deer Creek and Salmon Hole sites to 0.127 at the mouth of Antelope Creek site (\bar{x} = 0.022). Total catch per unit effort for all sites combined totaled 0.013 green sturgeon eggs/wmd (Table 1).

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 17 different females who spawned between April 2 and June 27, 2009 (Table 2). Fifty-five of fifty-six eggs analyzed were determined to have been fertilized. Nine of fifty-six eggs were dead (covered with fungus); the remainder appeared viable. Forty-one eggs were assessed for developmental stage using Detlaff et al. (1993) after fixation in EtOH. Embryonic developmental assessment indicated eggs were between stage 2 (just fertilized) and stage 29-30 (formation of S-heart). Most eggs were collected at stage 12 and 13 (early gastrulation; Table 2).

Egg diameter (length and width) was measured on 77% of the samples collected in the field prior to fixation with EtOH and 71% of the samples transferred to the laboratory (post fixation). By direct comparison, field egg diameter measurements (N = 33) were slightly larger for both width and length measurements. Field width and length measurements ranged from 3.25 to 4.48 mm (\bar{x} = 4.07 mm) and 3.72 to 5.02 mm (\bar{x} = 4.42 mm), respectively. Laboratory width and length egg diameter measurements ranged from 3.50 to 4.43 mm (\bar{x} = 3.78 mm) and 3.86 to 4.71 mm (\bar{x} = 4.12 mm), respectively. A simple t-test revealed significant differences between field and laboratory width measurements (t = -4.571, df = 64, P = <0.001). A Mann-Whitney Summed Rank Test revealed significant differences between field and laboratory length measurements (T = 806.5, N = 33, P =

<0.001). Results of these tests indicate differences in the accuracy of the two measurement techniques and likely egg shrinkage due to fixation in EtOH.

Egg mats sampled in water depths ranging from 0.5 to 13.6 m (Table 3). Comparisons of average set and retrieve depths for all sites combined were identical; valued at 4.8 m. Sample depths for eggs collected from all of the sites combined ranged from 0.8 to 9.4 m (\bar{x} = 4.7 m; Figure 6). Overall, green sturgeon eggs sampled from the RBDD sample site were found in depths ranging 1.0 to 7.9 m (\bar{x} = 4.9 m) *less* than the other three sites (Table 3).

Sacramento River flows during the sample period ranged between 142 to 460 m³s⁻¹ at RK 424.5 (Figure 7), RK 407.5 (Figure 8), RK 391 (Figure 9), RK 377 (Figure 10) and 161 to 470 m³s⁻¹ at RK 354/353 (Figure 11). Flows generally increased over the sample period due to Shasta/Keswick Dam releases during the primary agricultural irrigation season. During the sample period one spring storm event in early May resulted in a large spike on the hydrograph and corresponded to the peak flow values noted at all sample sites (Figures 7-11).

Sacramento River flows ranged from 156 to 460 m³s⁻¹ (\bar{x} = 250 m³s⁻¹) at Bend Bridge gauging station during the estimated spawning period at RK 424.5 (Figure 7) and RK 407.5 (Figure 8). Flows ranged from 210 to 460 m³s⁻¹ (\bar{x} = 289 m³s⁻¹) during the estimated spawning period at RK 391 (Figure 9) and RK 377 (Figure 10).

Turbidity sample values from the above RBDD sites ranged from 1.8 to 55.4 nephelometric turbidity units (NTU) throughout the sample period (\bar{x} = 5.6 NTU). During the estimated spawning period, turbidity ranged from 3.1 to 55.4 NTU (\bar{x} = 7.0 NTU). Turbidity sample values from the RBDD and below sites ranged from 2.3 to 29.3 NTU (\bar{x} = 3.6 NTU) throughout the sample period. During the estimated spawning period at RK 391 and RK 377, turbidity ranged from 2.8 to 14.2 NTU (\bar{x} = 3.6 NTU).

Water temperatures ranged from 9.7 to 15.8°C (\bar{x} = 13.3°C) at RK 424.5, 10.5 to 15.8°C (\bar{x} = 13.8°C) at RK 407.5, 10.6 to 16.3°C (\bar{x} = 14.0°C) at RK 391, 10.6 to 17.3°C (\bar{x} = 14.5°C) at RK 377, and 10.9 to 19.7°C (\bar{x} = 15.4°C) at RK 354 above the mouth of Deer Creek during the sampling period. During the estimated spawning period, water temperatures ranged from 10.8 to 14.2°C (\bar{x} = 12.7°C) at RK 424.5 (Figure 7), 11.0 to 14.8°C (\bar{x} = 13.1°C) at RK 407.5 (Figure 8), 15.4 to 15.7°C (\bar{x} = 15.5°C) at RK 391 (Figure 9), and 11.2 to 16.0°C (\bar{x} = 14.5°C) at RK 377 (Figure 10).

Spawning substrate surveys.— A single pass UVC spawning habitat survey was conducted at RK 407.5 on November 25, 2008 with the Sacramento River discharge at 132 m³s⁻¹. Beginning at the point furthest downstream the substrate consisted of scattered cobble imbedded in gravel and sand (Figure 12a). As the survey proceeded beyond the midpoint, the substrate was very homogeneous, predominantly gravel sized substrate (Figure 12b). Beyond the survey's midpoint, lava outcroppings and large boulders resulted in mild eddies and upwelling areas (perpendicular eddies). This segment had pockets of sand and small gravel which were deposited over gravel (Figure 12c and 12d). The smaller size class

substrates could be seen moving or migrating back and forth. In the final segment of the survey water velocity increased and sand was not apparent. The substrate appeared to be homogenous gravel and large cobble mix similar to that observed in the first half of the survey area (Figure 12e).

Multiple pass UVC surveys were performed within a known green sturgeon holding area at RK 354 and 353 in the Deer Creek confluence area (R. Corwin, USBR, pers. comm. and M. Thomas, UCD, pers. comm.). Surveys occurred on April 16, 2009 with river flows at $105 \text{ m}^3 \text{ s}^{-1}$. A single pass UVC survey through the RK 354 uppermost egg sampling location revealed large boulders that make up the river right bank (primarily rip rap placed for bank armoring; Figure 12f). Towards the center and river left bank the substrate was primarily cobble and large gravel (Figure 12g).

The substrate throughout RK 353, Deer Creek lower egg sampling sites, was found to be similar in composition. The substrate at the pool tail on river left consisted of cobble embedded with sand and gravel (Figure 12h). Substrate within the pool consisted of exposed bedrock with depressions that were partially filled with sand and gravel (Figure 12i). Large sections with >75% hardpan could be found within the deepest portions of the pool area. Upstream of the lower pool/glide, sand and woody debris (presumably deposited by Deer Creek) dominated the lower velocity areas (Figure 12j). Below the pool on river right, the substrate consisted of sand deposited in the slack water behind the point bar below the mouth of Deer Creek (Figure 12k). Below the mouth of the upper pool, a section of fine gravel was observed shifting around likely as a result of an eddy in the area. Closer to the thalweg, the sediment size increased to cobble with underlying hardpan and large cobble exposed in the main channel (Figure 12l).

Larval migration surveys.— Larval drift sampling occurred from April 29 to July 27, 2009. Wetted net time totaled 127 hours (7,623 minutes) during weekly standardized sampling efforts Monday through Friday nights (Table 4). RBDD Bypass Outfall site was sampled every other night generally from 20:00 to 01:00. Sampling at Bend Bridge (RK 415) was augmented after 5/28/09 due to noise complaints from local residents. Sampling of this site ceased at 22:00 for the remainder of the season and the other half of the night was sampled at Jelly's Ferry Bridge (RK 429), the next upstream bridge. Net set times ranged from 3 minutes to 75 minutes ($\bar{x} = 32$ minutes).

As noted in the egg sampling results section of this report, one major flow event occurred during the sampling season and Sacramento River conditions were primarily the result of water releases from Shasta/Keswick Dam (Figure 7). Turbidity values derived from surface grab samples ranged from 2.0 to 22.7 NTU ($\bar{x} = 5.5$ NTU). 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

tow. Sample depths were variable between sites but ranged from 0.7 to 3.9 m (\bar{x} = 1.6 m; Table 4). Surface velocities ranged from 0.9 ms^{-1} to 2.0 ms^{-1} (\bar{x} = 1.4 m s^{-1} ; Table 4).

Twenty-nine positively identified green sturgeon larvae were captured during the 2009 standardized sampling season entirely from the RBDD Bypass Outfall (RK 391). Larvae were sampled between a 37 day period between June 10 and July 17, 2009. Samples were collected on 6 dates within this period, primarily following the lowering of the RBDD gates. During the 37 day period 19 of 37 dates were not sampled due to winch failure and weekend non-sample days (Figure 13a). Following repairs and replacement of failed winch number one (a period of 13 days), the second winch failed within 10 days of operation. The third effort (outside of the 37 day capture period) and final repair attempt of winch number two lasted a mere 3 hours of operation and sampling of the 2009 season was discontinued on the night of July 27.

Total length of larvae sampled ranged from 23 to 28 mm (\bar{x} = 26 mm; Figure 14a). Of twenty-nine fish sampled, twenty one were morts and eight were released back to the river in good condition. All morts were analyzed to determine estimated spawn dates and developmental stage using Dettlaff et al. (1993). Estimated spawn dates for the samples collected between July 13 and July 17, 2009 were between June 15 and June 25, 2009 (Figure 14b).

Experimental larval sampling surveys. — On June 9/10 and July 6/7, 2009 concurrently deployed gear was used to sample for green sturgeon larvae at RK 377 and RK 424.5, respectively. The three gear types (D-net, fykes, and seines) were deployed at or near sunset on each occasion. No green sturgeon larvae were sampled on July 6/7 at the above RBDD site known as Massacre Flats (RK 424.5) by any of the three gear types.

Sixteen green sturgeon larvae were sampled on June 9/10 in very close proximity to a confirmed green sturgeon spawning site (Poytress et al. 2009) using a benthic D-net (Table 4). The net was deployed on twelve separate occasions throughout the night beginning at 22:13 on 6/9/09 through 6:16 on 6/10/09 for a total sample time of 319 minutes (Table 4). Net set times ranged from 15 to 30 minutes (\bar{x} = 26.4 minutes). Non-sample time between sets was typically minutes, yet on two occasions the anchor system gave way and had to be redeployed resulting in a loss of 1 hour of sample time between 1:20 and 2:20.

Green sturgeon larvae sampled by D-net were sampled in 2.4 to 3.3 m of water (\bar{x} = 3.0 m) and in a surface water velocity of 0.6 m s^{-1} (Table 4). Water temperature during the overnight sample period decreased throughout the sample period from 17.3 to 14.7 C. Capture of green sturgeon larvae increased as temperature decreased and peaked prior to midnight showing a bi-modal distribution pattern (Figure 15).

Fyke nets were placed slightly downstream of the spawning site, one placed on river right (west river margin) and one mid-channel on a partially submerged gravel bar. Both fyke nets were placed in approximately 0.6 m of water or roughly half the depth of the fyke opening. The first fyke net samples at 23:30 on 6/9/09 yielded zero green sturgeon larvae and a variety of cyprinids and cottids as well as some American Shad eggs (*Alosa*

sapidissima). Light debris loads and no mortality of captured fishes allowed us to sample the remainder of the night continuously. The final sample of the period was collected at 7:15 on 6/10/09. Various cyprinids and shad eggs were again found in both fykes. Three green sturgeon larvae were sampled by the mid-channel fyke net and zero were captured by the west river margin fyke net.

Seining activities conducted periodically throughout the night were unsuccessful at capturing green sturgeon larvae. Samples were likely compromised as substrates were congested with vegetation and distances from shore were extremely limited due to swift currents in the area. Catch on all occasions yielded small numbers of fall run Chinook (*Oncorhynchus tshawytscha*), Sacramento Pikeminnow (*Ptychocheilus grandis*) and Sacramento Sucker (*Catostomus occidentalis*).

Discussion

Through the sampling and positive identification of green sturgeon eggs using artificial substrate mats, four spawning areas in the Sacramento River were confirmed in 2009. Eggs were sampled for the second consecutive season from the Sacramento River at RK 424.5, RK 391, and RK 377 and for the first time at RK 407.5. Green sturgeon eggs were sampled on multiple occasions from multiple spawning events (Table 2) at each of the four spawning sites (Figure 5). Thirty-three percent more eggs were sampled in 2009 ($N = 56$) in comparison to 2008 ($N = 42$).

Egg sampling surveys above RBDD.— Eggs were first sampled from RK 424.5, 33.5 river kilometers above the RBDD 74 days before the lowering of the RBDD gates which creates a barrier to upstream migrating sturgeon (Brown 2007). Green sturgeon eggs were collected on the first day of sampling following the initial egg mat deployment at this furthest most upstream site. Initiation of sampling was based on the results of the 2008 surveys and the presence of acoustic tagged fish detected in the upper Sacramento River in mid-March of 2009 (R. Corwin, USBR, pers. comm.). A total of 9 green sturgeon eggs were sampled from this site from April 2 to May 21, 2009 indicating spawning occurred only before the RBDD gates were lowered on June 15, 2009 (Figure 7). Two green sturgeon eggs were collected 16.5 river kilometers above RBDD at RK 407.5. The two eggs were sampled between May 28 and June 1, 2009 (Figure 8). The estimated spawning period of the eggs sampled above RBDD ranged from April 2 to May 26, 2009 (Table 2). The last egg collected above RBDD on 6/1/09 was crushed and decayed (fungal growth) and the stage of development could not be determined. Overall the analyzed eggs collected above RBDD were estimated to be from at least six different spawning events within an eight week period prior to the June 15 RBDD gate closure.

Sampling of the site located at RK 423 did not detect the presence of green sturgeon eggs in 2009. Sampling effort in terms of wetted mat days was greater at this location than at either RK 424.5 or RK 407.5 where spawning activity was confirmed (Table 1). The site was determined to have acoustic tagged green sturgeon present (M. Thomas, UCD, pers. comm.) in 2008 and thus was chosen as a probable spawning area. Conditions of the site are somewhat similar to the RK 424.5 site, but may not have the correct combination of unique

variables necessary for green sturgeon spawning. Comparable river depth and some degree of complex hydraulics were present at the site, but substrate was not confirmed due to lack of resources (i.e., not surveyed). Temperatures were commensurate with other confirmed spawning areas as this site was situated within 1.5 river kilometers of the site where eggs have been sampled in two consecutive years. Sturgeon were observed breaching by field crews checking egg mats in 2009 at this site on two occasions, yet spawning activity was not confirmed. Overall, large congregations of sturgeon were not detected at this site and it may be of importance as a holding or staging area in close proximity to a spawning area. Alternately, the sampling of eggs is inherently difficult in some of these areas, and it is possible spawning occurred at this site without detection.

Egg sampling surveys at RBDD.—The RBDD gates were lowered a month later than in previous years due to new regulations imposed, in part, to aid the passage of green sturgeon adults to upper Sacramento River spawning habitat (NMFS 2009). Two eggs were sampled on June 29 and July 1, respectively from samples collected by a mat placed just downstream of gate 3's abutment. This area, located immediately downstream of the eastern half of the dam, did not appear to have the bed mobility issues that were detected with mats placed below the western half of the dam. Mats placed below the western half of the dam were often partially to mostly buried in sand and small gravel within a couple of hours of placement; oftentimes compromising the samples. The mats placed below the eastern half of the dam were much less impacted by substrate mobilization. Consequently, the effects on green sturgeon eggs is likely minimal or commensurate with that occurring in unobstructed settings. Evidence of minimal impact to the eggs sampled on the east side of RBDD is noted by the healthy appearance of eggs sampled in 2009 (Table 2) that were in the later stages of development (23-30; Detlaff et al 1993).

Sand and gravel movement and aggradation were noted in the 2008 sample season (Poytress et al 2009) as a concern with respect to sturgeon egg deposition and the potential for sub-lethal or lethal effects to incubating eggs (Kock et al. 2006). The 2009 data supports this concern, but for the western side of the dam only. The substrate on the west side of the dam often has significant annual contributions of mud, sand, and gravel from Red Bank Creek, a highly erodible intermittent tributary. Red Bank Creek has been estimated to yield an average annual sediment load of 41 acre-feet (66,000 cubic yards) of sediment at its mouth immediately upstream of RBDD (USBR 1992). This poses a problem to green sturgeon when RBDD gates are lowered in the spring and the river bed below the west side of the dam becomes mobilized when high velocity hydraulics are formed by water passing below the partially opened dam gates. The result is sustained movement of the deposits, assumedly until a time when substrate equilibrium is reached. With the lowering of the gates during the green sturgeon spawning period (Poytress et al. 2009), those individuals that spawn on the west side of the dam may be more susceptible to reduced productivity or recruitment failure if eggs are deposited in this area.

Egg sampling surveys below RBDD.—The majority of green sturgeon eggs sampled in 2009 (77%; $N = 43$) were sampled at RK 377 (Table 2); 14 river kilometers below the RBDD. Eggs were sampled from this site over a two month period with the first egg sampled in late April and the last egg sampled in late June (Figure 5). Eighty-one percent of

eggs sampled at this site were collected before the June 15 RBDD gates lowered period. Egg analysis estimated that egg samples collected from this site were from 10 different females or spawning events. Analysis also revealed a large amount of variation in developmental stage of samples, ranging from stage 2 to stage 25 (Detlaff et al. 1993). One egg was determined to be unfertilized (Table 2) and was the first sample in two years found in this condition.

The most effort, in wetted mat days, was expended at RK 354/353, the Deer Creek site. Effort totaled 603 wetted mat days (Table 1) and multiple microhabitats were sampled. The furthest upstream microhabitat, known as Deer Creek Upper Riffle, was discontinued after flows reached $\sim 340 \text{ m}^3\text{s}^{-1}$ in the area due to safety concerns and problems with anchors getting trapped in large boulder substrates (Figure 12f). The majority of effort focused on a pool area with some degree of complex hydraulics, seemingly suitable depths and temperatures, and small areas of gravel substrates (Poytress et al. 2009).

Acoustic transmitter tagged green sturgeon were detected at this site, the lowermost in the study area, as early as mid-March 2009 in small numbers and for a period of several weeks (R. Corwin, USBR, pers. comm.). Sampling commenced within two weeks of the first detection. Sampling was conducted above and below the mouth of Deer Creek as it was determined that multiple, relatively small areas were determined to have green sturgeon holding within them. Shipboard tracking results from 2008 (M. Thomas, UCD, unpublished data) indicated sturgeon often moved between specific microhabitats at this location to the confirmed spawning location at RK 377 in a “ping pong” fashion. Even with significant effort, spawning activity was not detected at this site. Similar to the other unconfirmed, suspected spawning area above the dam (RK 423) sampled in 2009, this site may be of significance in terms of a holding or staging area and may not have the correct combination of variables to induce spawning activity. Large numbers of adults were not detected in this area by acoustic (R. Corwin, USBR, pers. comm.) or side scan sonar data yet breaching activity was detected on a few occasions by field crews and collaborators. Alternately, spawning activity simply may have gone undetected at this site.

Spawning substrate surveys.—Limited effort was expended performing UVC substrate surveys in 2009. Only two of three new egg sample sites were surveyed (RK 407.5 and RK 354/353). Sites surveyed in 2008 (RK 424.5 and RK 377) were not resurveyed to detect changes in habitat that could have possibly occurred as a result of high winter flows. For the most part, 2009 was considered a less than average precipitation year and flows did increase appreciably for considerable amounts of time. By simple surface observation, RK 424.5 and RK 377 did not appear different in 2009 compared to 2008 (i.e., pools did not change in physical appearance or flow patterns due to scour or deposition).

Surveys performed in the high velocity RK 407.5 egg sample site of the Sacramento River yielded insight into the varied substrate composition of the area. The high velocity, turbulent areas appeared to produce areas of small to medium sized gravel consistent with areas where eggs have consistently been sampled (Poytress et al. 2009). Likely, this reach of river is variable between years and suitable spawning areas may change as substrates shift from year to year, on a micro-habitat scale. Annual geo-referenced surveys of this reach may provide insight into the degree of substrate variability associated with this spawning area.

Surveys performed in the large area above and below the mouth of Deer Creek (RK 354/353) indicated only a small area of seemingly homogenous gravel beds, as seen at other sample sites where green sturgeon eggs were and have been collected (Poytress et al. 2009). Substrate identified at the Deer Creek site was predominantly sand or hard pan bed rock with large cobbles. This may be an important clue as to why spawning activity was not detected. Additionally, only a few fish were detected at this site at any one time indicating it may be of high value for staging as opposed to spawning. Some degree of complex currents were present, but, standing waves resultant from very high velocity current were not observed which may also be an important variable for green sturgeon spawning habitat as well.

Larval migration surveys.— Sporadic success was achieved using a benthic D-net to sample migrating green sturgeon larvae in 2009 (Figure 13a). Twenty-five more green sturgeon larvae were sampled from the RBDD Bypass Outfall in 2009 compared to 2008; translating to a 625% increase in catch. Sampling effort was more concentrated per night and fewer sites were sampled overall. The sample design may have resulted in zero green sturgeon samples being collected at Bend Bridge, below known spawning grounds, since sampling was not conducted due to noise complaints during peak catch hours. Conversely, sample location may have resulted in zero green sturgeon samples at Jelly’s Ferry Bridge as spawning has not been confirmed above this sample site. Abundance of adult green sturgeon was unknown as spawner abundance surveys were not conducted. Abundance levels of juveniles, as sampled by this project are therefore inconclusive, yet the data suggests a greater number of adults were present above the RBDD sample site in 2009 as compared to 2008.

Unfortunately, sampling was halted on three occasions due to inadequate winch equipment sampling in high velocity mid-channel areas of the Sacramento River where green sturgeon larvae have been repeatedly sampled. The goal of this particular task of study was to define temporal and spatial distribution patterns. These efforts were compromised due to a lack of adequate equipment. As larval green sturgeon samples began to be collected in early June, the first winch failure occurred resulting in a loss of 19 potential sampling days. Shortly after returning to sample in early July, daily catch peaked for the season and then equipment failure resulted in the loss of sampling days for most of the remainder of July (Figure 13a). The third and final winch failure occurred on July 27 and sampling was discontinued for the season. Original plans called for sampling until mid-August, but the time constraints to acquire replacement parts and make repairs to the inadequate system made the continuation of sampling impractical.

Comparison of targeted and non-targeted larval surveys.— From the limited data acquired through the D-net sampling, catch began in early June and nightly catch peaked in mid-July and ceased shortly thereafter (Figure 13a). In an effort to derive the most information possible from the 2009 sample efforts, a catch comparison was conducted using USFWS rotary screw trap data (See Gaines and Martin 2002) acquired directly below RBDD and D-net data acquired from the RBDD Bypass outfall 500m downstream of RBDD. Rotary trapping occurred 7 days per week throughout the standardized D-net sample period, except for a twelve day period in mid-June associated with the lowering of the RBDD gates

and related operations of the RBDD. By direct comparison, the first catch of green sturgeon larvae by D-net occurred nearly a month later than by rotary screw trap (Figure 13b). The primary period of sturgeon catch by rotary traps occurred in June to mid-July and was similar, in trend, to the period when D-net catch of larvae occurred. Rotary trap catch of sturgeon larvae was considerable during the time when winch failure precluded D-net sampling. Moreover, the last date samples were collected by either method was July 17. Directed effort (D-net) may have extended the capture period had winch failure not been an issue, but it is notable that the final night of captures was identical using a targeted and non-targeted approach (Figure 13a/b). Overall, total catch derived from both methods was similar between D-net ($N = 32$) and the array of rotary traps ($N = 29$).

Targeted sampling resulted in the collection of a very narrow size range of fish lengths. Rotary traps, on the other hand, sampled a wider range of fish sizes even though median total lengths were within 0.4 mm (Figure 14a). Additionally, the wider range of fish sizes sampled by rotary traps corresponds to a wider range of estimated sturgeon spawning dates.

Of particular interest is that from the subset of samples collected by rotary traps and analyzed in the laboratory (i.e., incidental mortalities only) all had an estimated spawn date *prior* to the RBDD gates being lowered on June 15, 2009. In contrast, all but one fish analyzed from the D-net samples were estimated to have been produced from spawning activity *after* the lowering of the RBDD gates (Figure 14b). Over many years, theories have arisen that rotary traps only sample sturgeon that are from the immediate area between the traps and the dam due to proximity to RBDD, a confirmed spawning location (Brown 2007, Poytress et al. 2009). The results of these data would indicate the fish captured by rotary traps at RBDD are from spawning areas above the dam as adults are not seen to congregate in great numbers prior to the dam gates being lowered each spring. Furthermore, spawning is not suspected to occur in the immediate area below RBDD without the dam gates in the lowered position. The fish sampled by D-net, on the other hand, appear to have been collected from the spawning aggregates that form after the gates are lowered which is in close proximity to the D-net sample site. Moreover, data collected from one of two overnight D-net sampling experiments (described in more detail below) occurring within a confirmed spawning area at RK 377 (Poytress et al. 2009) gives further evidence that D-nets sample newly emerging larvae most effectively in close proximity to spawning grounds.

Experimental larval sampling surveys/nocturnal distribution pattern.— 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 sampling occurred primarily between the hours of 20:00 and 01:00 each night, experimental all night sampling within confirmed spawning grounds yielded limited nocturnal distribution data on one of two occasions. On June 9/10, 2009 sampling at RK 377 with a D-net at ½ hour intervals throughout the nocturnal hours yielded comparable hourly distribution data to standardized sampling (Figure 15). The subset of nocturnal hours sampled by the standardized sampling (1st ½ of nighttime

period) indicated a similar trend in distribution as the experimental data when seasonal catch was stratified by hour for larvae collected throughout the 37 day catch period. The peak catch was noted by both sample regimes as occurring a couple hours after dark and prior to midnight as temperatures began to decline (Figure 15).

The increase in catch noted as the river temperature decreased may be an important function related to the energetics of this critical life stage of green sturgeon. Allen et al. (2006) noted increased growth rates of green sturgeon when subjected to diel temperature fluctuations. Additional studies on various sturgeon species (as noted in Allen et al. 2006) have also associated fast growth rates with diel temperature cycles. Interestingly, the mean optimal overall growth temperature (cycle 19 to 24 °C) noted in Allen et al (2006), was approximately 5 degrees warmer than conditions noted in the Sacramento during the all night experiment in June.

Flow and resultant temperature management of the Upper Sacramento River system in the spring and summer of each year is focused primarily to protect Endangered winter-run Chinook salmon spawners and allelins (NMFS 2009). The current temperature management strategy may have unrealized deleterious effects on green sturgeon. The low temperature requirements for successful Chinook egg incubation and hatching, relative to green sturgeon, may have multiple negative effects on the Sacramento River green sturgeon spawning population. Effects likely include: habitat confinement (restriction to lower, warmer river reaches) or reduced habitat quality for spawning adults, sub-optimal temperatures for egg incubation (Van Eenennaam et al. 2005) in upper reaches of the Sacramento River above RBDD, as well as sub-optimal temperatures for exogenously feeding green sturgeon larvae (Mayfield and Cech 2004). Management of the Sacramento River's water resources may prove to be increasingly challenging when considering differing needs of very different fish species now listed as Endangered and Threatened under the Federal Endangered Species Act.

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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)
Massacre Flats (RK 424.5)	Pool	3/30/09	7/30/09	3	316.1	9	0.028
Salmon Hole (RK 423)	Pool/Glide	3/30/09	7/30/09	4	395.0	0	0.000
Turkey Beach (RK 407.5)	Pool/Glide	3/30/09	7/30/09	3	256.8	2	0.008
RBDD (RK 391)	Dam ¹	6/26/09	7/31/09	4	147.5	2	0.014
Antelope Creek (RK 377)	Pool	3/31/09	7/31/09	3	338.8	43	0.127
Deer Creek (RK 354)	Run	3/31/09	5/1/09	3	73.5	0	0.000
Deer Creek (RK 354)	Pool	3/31/09	7/31/09	4	408.4	0	0.000
Deer Creek (RK 353)	Glide	3/31/09	6/5/09	2	121.3	0	0.000
Total				26	2,057.4	56	0.013

¹ 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 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	River KM	Egg Count	Spawn Date / Time	Stage	Comments
4/2/09	424.5	1	4/2/09 / 8:30	2	Just fertilized, no cleavage.
4/6/09	424.5	1	4/3/09 / 3:00	19	Early neurulation
4/6/09	424.5	1	4/5/09 / 8:30	13	Early gastrulation
4/6/09	424.5	1	4/5/09 / 22:30	10-11	Late cleavage to early blastula
4/6/09	424.5	1	-	-	Fungused and crushed
4/23/09	424.5	1	-	-	Fungused and crushed
4/23/09	424.5	1	4/22/09 / 2:30	13	Gastrulation
4/23/09	424.5	1	4/21/09 / 10:30	18	Very early neurulation
4/24/09	377	1	4/23/09 / 6:00	3	Grey crescent
4/24/09	377	1	-	-	Mottled and crushed
4/28/09	377	1	-	-	Fungused and crushed
4/28/09	377	1	-	-	Fungused and crushed
4/28/09	377	1	-	-	Fungused and crushed
5/12/09	377	1	5/10/09 / 6:30	19	Early neurulation
5/12/09	377	1	5/12/09 / 4:30	5	Second cleavage (4-cell stage)
5/12/09	377	1	5/12/09 / 8:30	2	Just fertilized
5/12/09	377	1	5/12/09 / 4:30	9	64-cell stage
5/12/09	377	1	5/12/09 / 4:30	9	Semi-crushed (similar to 64-cell stage egg above)
5/14/09	424.5	1	-	-	Crushed and mottled
5/27/09	377	1	5/25/09 / 22:30	16	-
5/27/09	377	1	5/26/09 / 16:00	10	Late cleavage
5/27/09	377	1	5/26/09 / 16:00	10	Late cleavage
5/27/09	377	1	5/26/09 / 22:30	8	32-cell stage
5/27/09	377	1	5/26/09 / 22:30	8	Crushed
5/27/09	377	1	-	-	Fungused and Crushed
5/27/09	377	1	-	-	Fungused and Crushed
5/28/09	407.5	1	5/26/09 / 8:00	18	Very early neurulation
5/29/09	377	1	5/28/09 / 10:00	13	Early gastrulation
5/29/09	377	1	5/28/09 / 10:00	13	Early gastrulation
5/29/09	377	1	-	-	Swirly pigment, unfertilized

Table 2 Continued.

Date	River KM	Egg Count	Spawn Date/Time	Stage	Comments
5/29/09	377	1	5/28/09 / 10:00	13	Early gastrulation
6/1/09	407.5	1	-	-	Fungused and crushed
6/2/09	377	1	-	-	Yolk extruding from chorion
6/5/09	377	1	6/4/09 / 23:30	6-7	8-16 cell
6/5/09	377	1	6/4/09 / 23:30	6-7	8-16 cell
6/5/09	377	1	-	-	Yolk extruding from chorion
6/5/09	377	1	6/4/09 / 7:30	17	-
6/5/09	377	1	6/4/09 / 10:30	15	-
6/5/09	377	2	6/5/09 / 1:00	10	Adhered together; late cleavage
6/5/09	377	1	6/5/09 / 4:00	4	First cleavage starting
6/5/09	377	1	6/5/09 / 5:00	4	First cleavage
6/5/09	377	1	6/5/09 / 6:00	6	4-8 cell
6/5/09	377	1	-	-	Fungused and crushed
6/12/09	377	1	6/12/09 / 2:30	7-8	16-32 cell
6/12/09	377	1	6/12/09 / 2:30	7-8	16-32 cell
6/16/09	377	1	6/13/09 / 5:00	16	-
6/16/09	377	1	-	-	Crushed
6/16/09	377	1	6/14/09 / 8:30	18-19	Early neurulation
6/16/09	377	1	6/14/09 / 8:30	18-19	Early neurulation
6/23/09	377	1	6/20/09 / 2:00	25	-
6/23/09	377	1	6/20/09 / 2:00	23	-
6/23/09	377	1	6/20/09 / 2:00	24	-
6/23/09	377	1	6/20/09 / 2:00	25	-
6/29/09	391	1	6/27/09 / 1:00	23-24	Mid-neurulation
7/1/09	391	1	6/26/09 / 13:00	29-30	S-heart formation
Total		56			

Table 3. Summary of egg mat sample depths and green sturgeon egg sample depths recorded during the 2009 green sturgeon egg mat sampling season.

Sample Location	Microhabitat	Sample Depths (m)			GST Egg Sample Depths (m)		
		Minimum	Average	Maximum	Minimum	Average	Maximum
Massacre Flats (RK 424.5)	Pool	2.6	5.8	13.6	4.9	5.4	6.8
Salmon Hole (RK 423)	Pool/Glide	1.1	5.5	12.3	-	-	-
Turkey Beach (RK 407.5)	Pool/Glide	3.8	7.5	9.8	6.6	8.0	9.4
RBDD (RK 391)	Dam ¹	0.5	1.2	2.7	0.8	1.1	1.5
Antelope Creek (RK 377)	Pool	1.3	4.7	8.9	2.5	4.5	7.9
Deer Creek (RK 354)	Run	2.3	3.2	4.0	-	-	-
Deer Creek (RK 354)	Pool	2.7	4.2	6.3	-	-	-
Deer Creek (RK 353)	Glide	3.1	5.9	7.5	-	-	-

¹ 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), net depth and surface velocities for samples collected during the 2009 green sturgeon larvae sampling project on the Sacramento River, CA.

Sample Type	SampleSite	Effort (min)	GST Catch	CPUE	Depth (m)			Velocity (m/sec)		
					Min	Ave	Max	Min	Ave	Max
Standard	Jelly's Ferry Bridge (RK 429)	1,029	0	0.000	0.9	2.3	3.9	0.8	0.9	1.1
Standard	Bend Bridge (RK 415)	2,437	0	0.000	0.7	2.0	3.2	0.7	1.0	1.3
Standard	RBDD Bypass Outfall (RK 391)	4,157	29	0.007	0.7	1.3	1.6	0.9	1.7	2.0
Experimental	Massacre Flats (RK424.5)	338	0	0.000	-	-	-	0.6	0.6	0.6
Experimental	Mouth of Antelope Creek (RK377)	319	16	0.050	2.4	3.0	3.3	1.0	1.0	1.0
Total		8,280	45	0.005						

Figures

2009 Green Sturgeon Sampling Locations

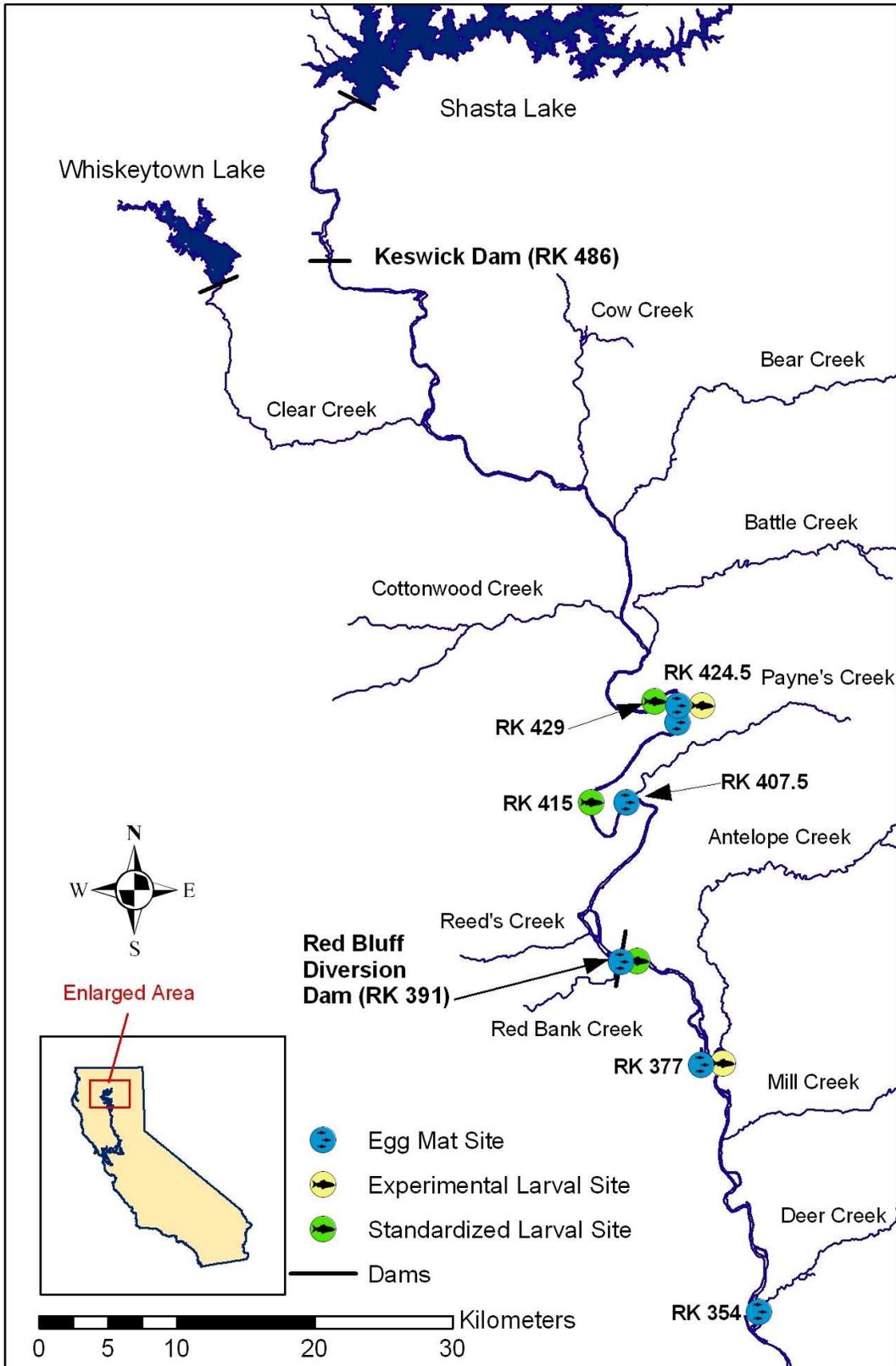


Figure 1. Green sturgeon egg and larval sample sites in the upper Sacramento River, CA.



Figure 2. Artificial substrate sampling gear used to sample for green sturgeon eggs in the upper Sacramento River; CA; a) egg mat; b) egg mat carrier; c) removable mesh net used to filter rinse water.



Figure 3. Underwater video camera with sounding weights and protective carrier positioned in deployment apparatus (Groves and Garcia 1998).



Figure 4. Benthic D-net attached to frame (bucket not attached) used to sample green sturgeon larvae on the upper Sacramento River, CA.

2009 Sacramento River Green Sturgeon Egg Sample Collection Dates

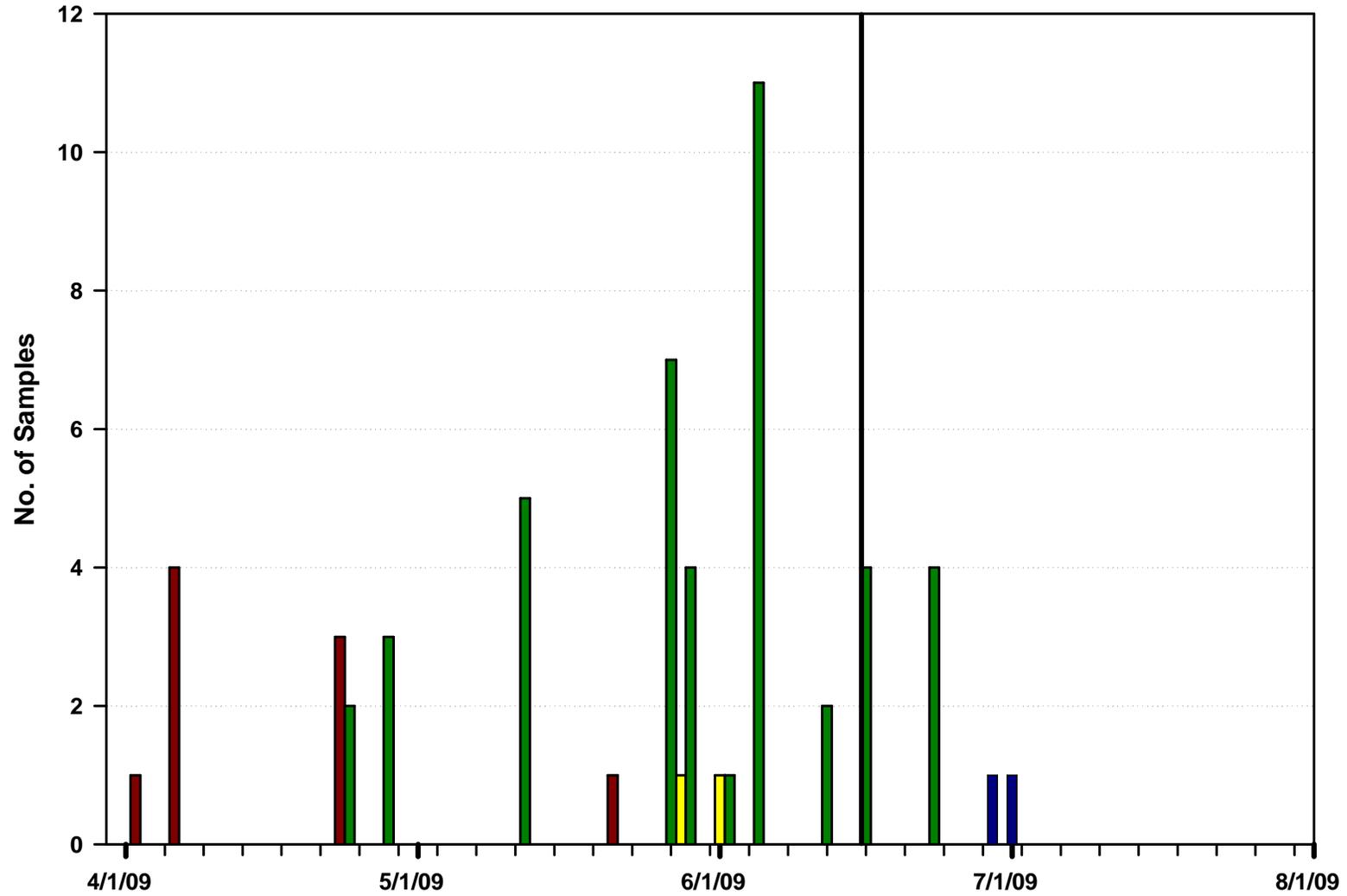


Figure 5. Temporal distribution of green sturgeon egg samples collected at RK 424.5 (red bars), RK 407.5 (yellow bars), RK 391 (blue bars), and RK 377 (green bars) on the Sacramento River, CA. Black vertical line indicates RBDD gate closure on June 15, 2009.

Sacramento River Green Sturgeon Egg Sample Depths

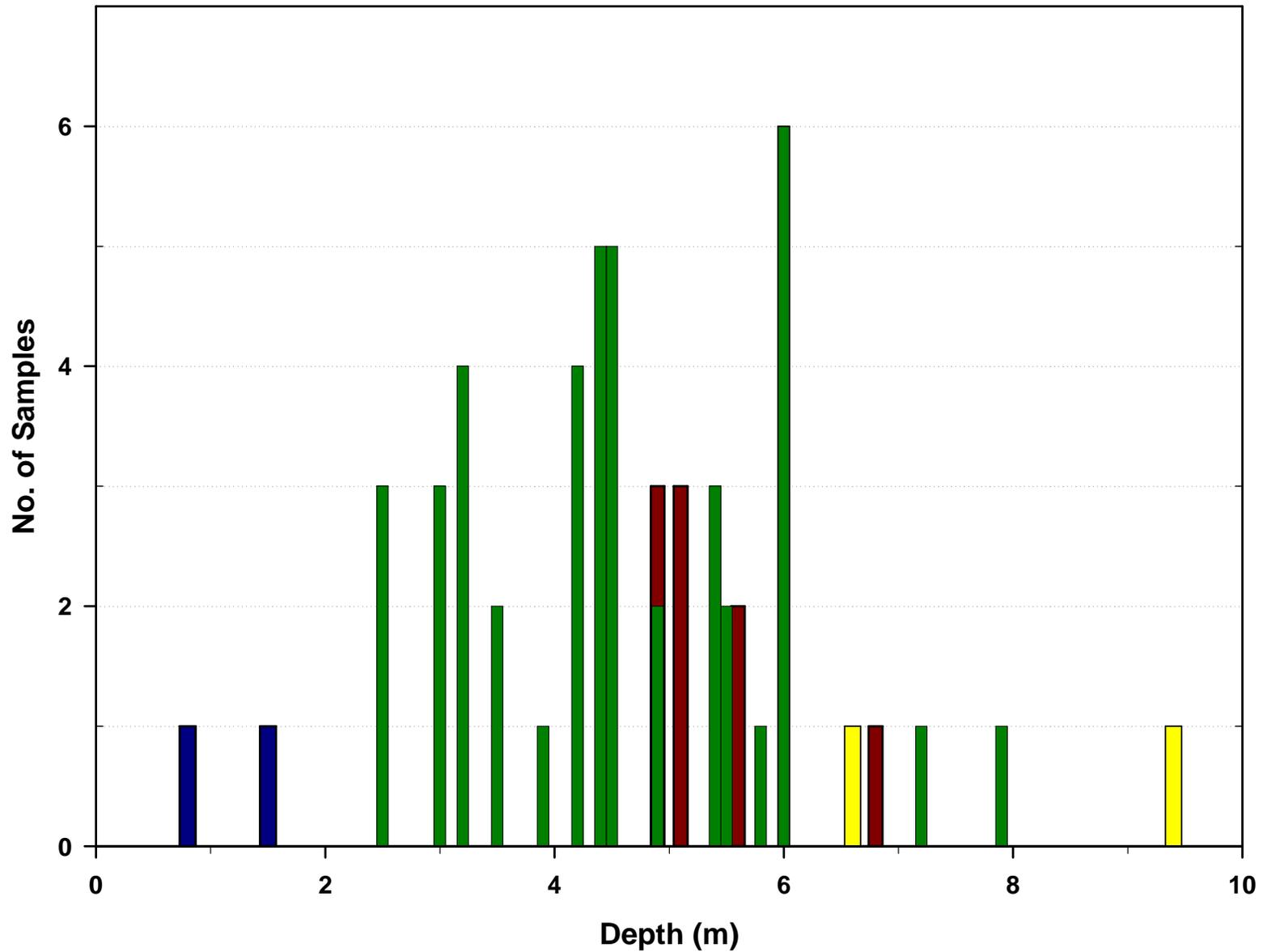


Figure 6. River depth of green sturgeon eggs sampled from egg mats at RK 424.5 (red bars), RK 407.5 (yellow bars), RK 391 (blue bars), and RK 377 (green bars) on the Sacramento River, CA for the period April 2 - July 1, 2009.

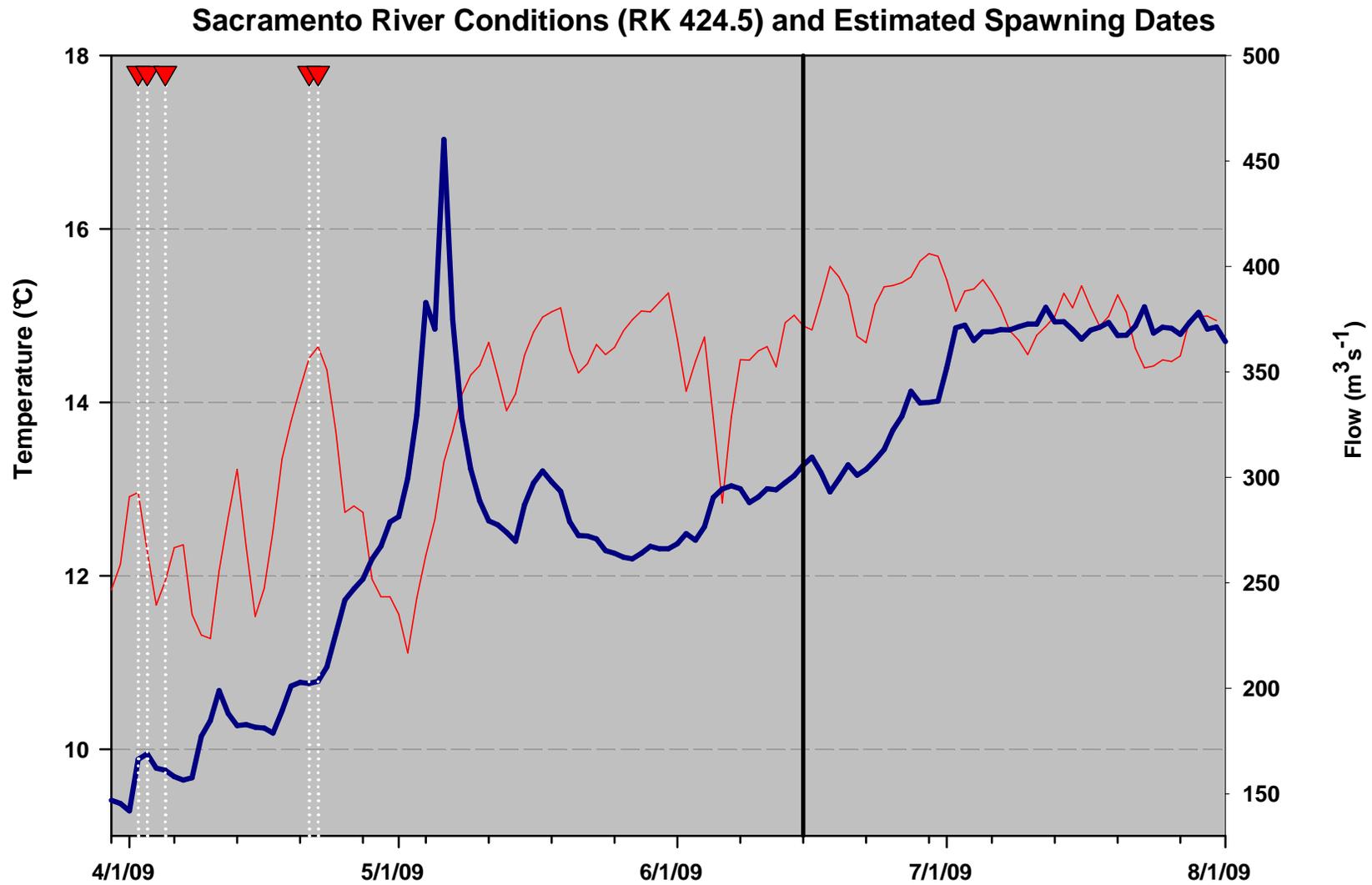


Figure 7. Estimated green sturgeon spawning dates (inverted red triangles), Sacramento River mean daily flow (dark blue), and mean daily temperature (red) at Massacre Flats (RK 424.5). Black vertical line indicates RBDD gate closure on June 15, 2009.

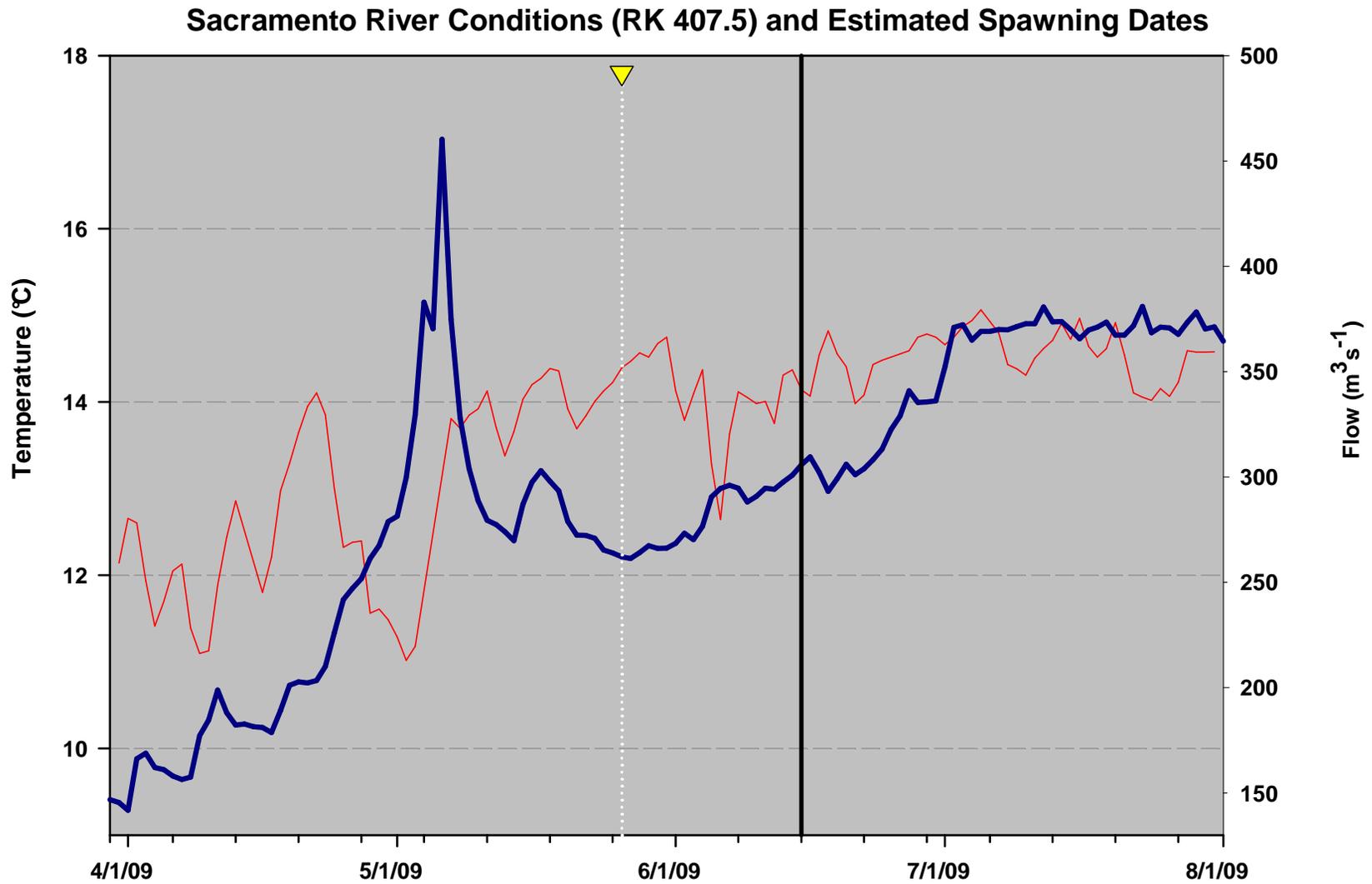


Figure 8. Estimated green sturgeon spawning dates (inverted yellow triangle), Sacramento River mean daily flow (dark blue), and mean daily temperature (red) at Turkey Beach (RK 424.5). Black vertical line indicates RBDD gate closure on June 15, 2009.

Sacramento River Conditions at RBDD (RK 391) and Estimated Spawning Dates

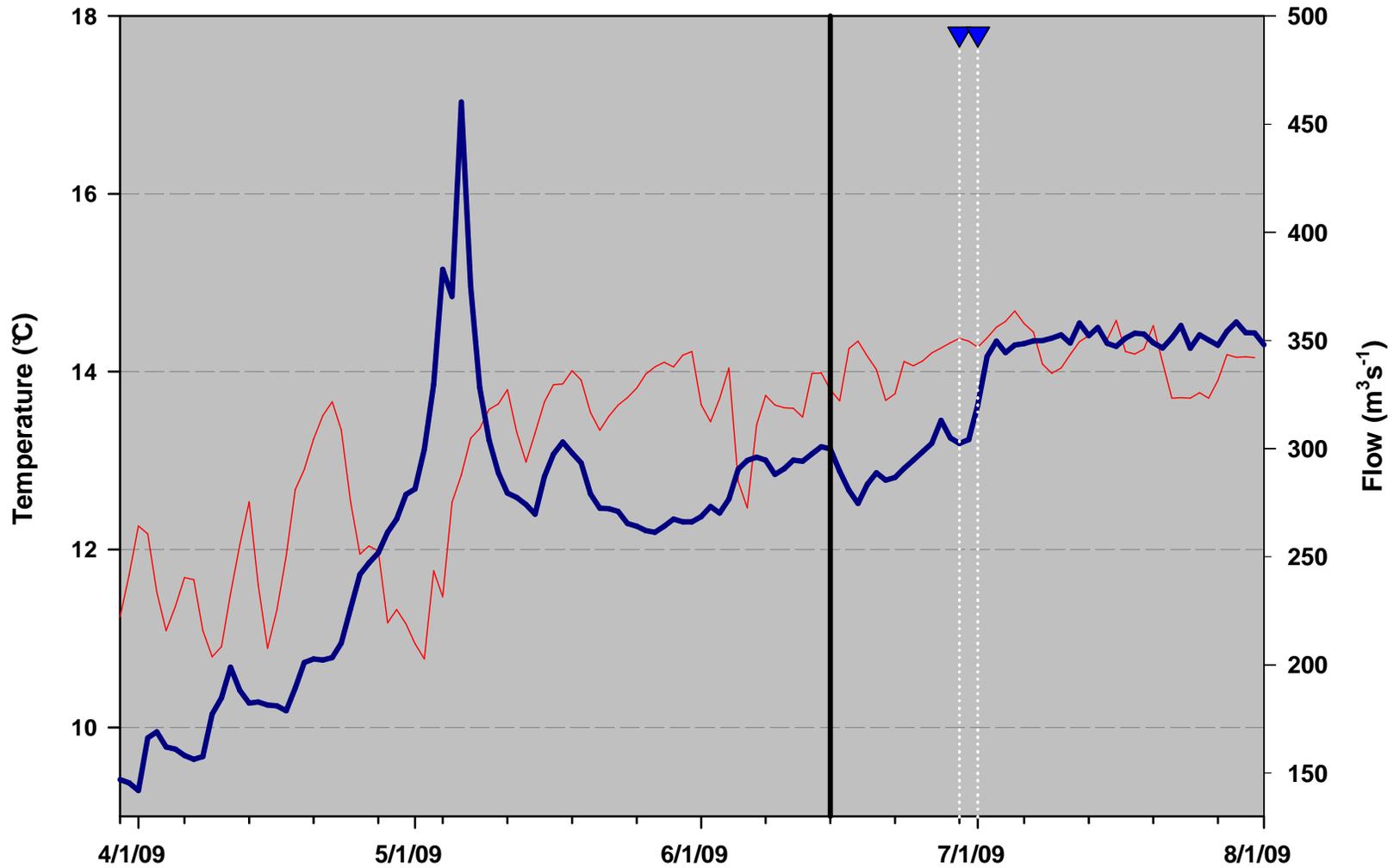


Figure 9. Estimated green sturgeon spawning date (inverted blue triangle), Sacramento River mean daily flow (dark blue), and hourly temperature (red) at RBDD (RK 391). Black vertical line indicates RBDD gate closure on June 15, 2009.

Estimated Spawning Dates and Sacramento River Conditions (RK 377)

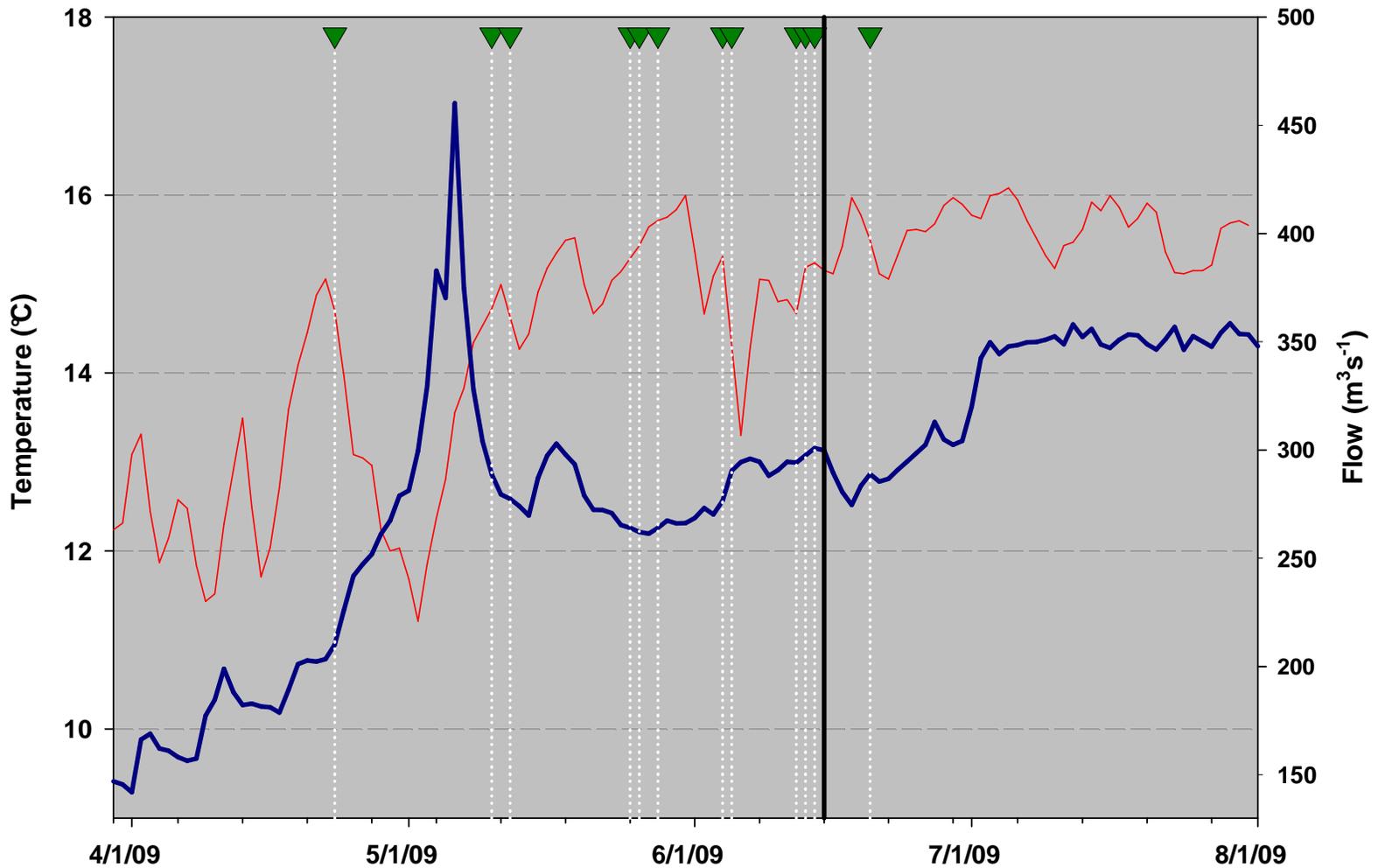


Figure 10. Estimated green sturgeon spawning dates (inverted green triangles), Sacramento River mean daily flow (dark blue), and mean daily temperature (red) at mouth of Antelope Creek (RK 377). Black vertical line indicates RBDD gate closure on June 15, 2009.

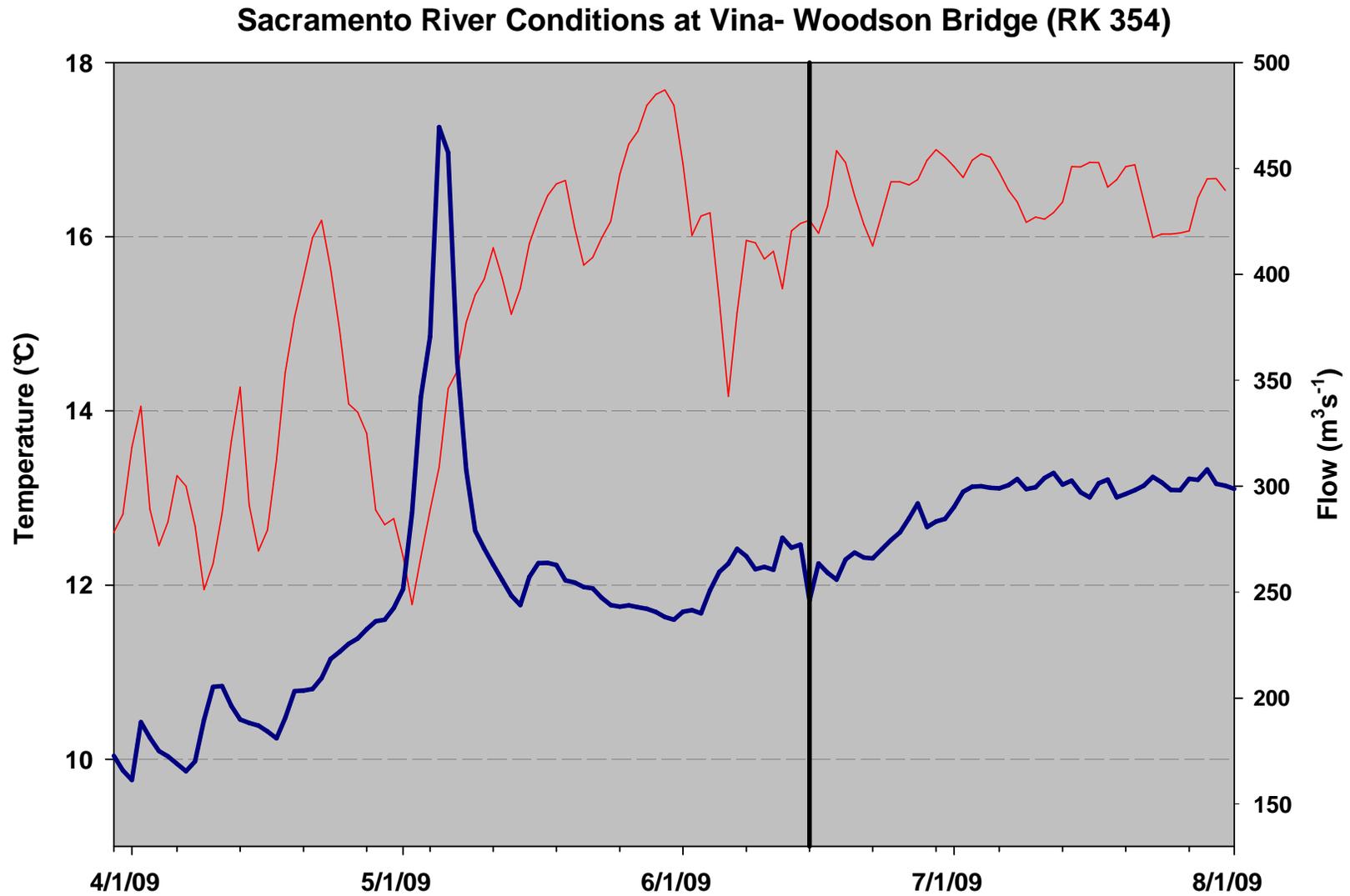


Figure 11. Sacramento River mean daily flow (dark blue), and mean daily temperature (red) at mouth of Deer Creek (RK 354). Black vertical line indicates RBDD gate closure on June 15, 2009.

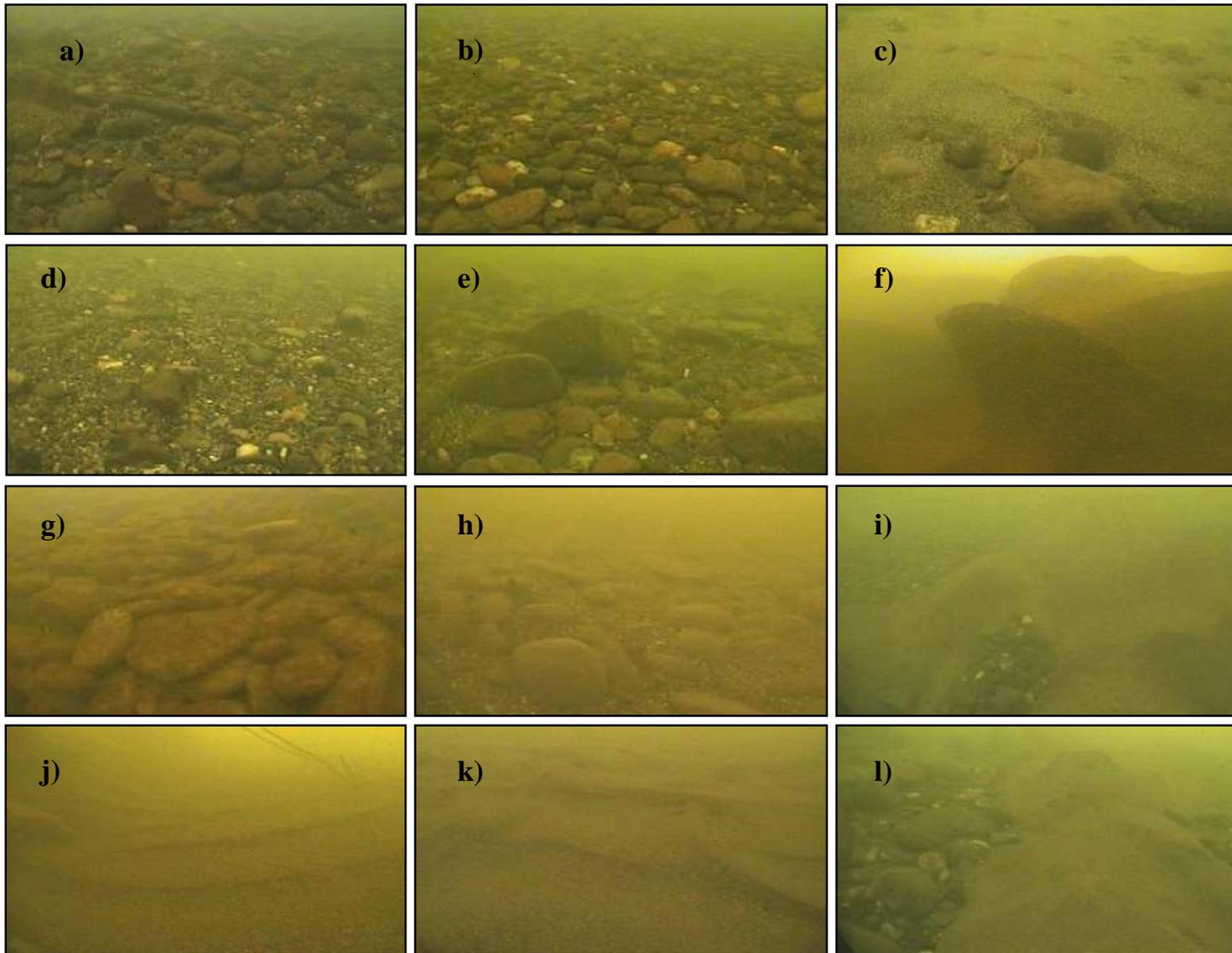


Figure 12. Underwater video camera snapshots of substrate at RK 407.5 (a-e) and RK 354/353 (f-l).

2009 Temporal Distribution of Green Sturgeon Captures

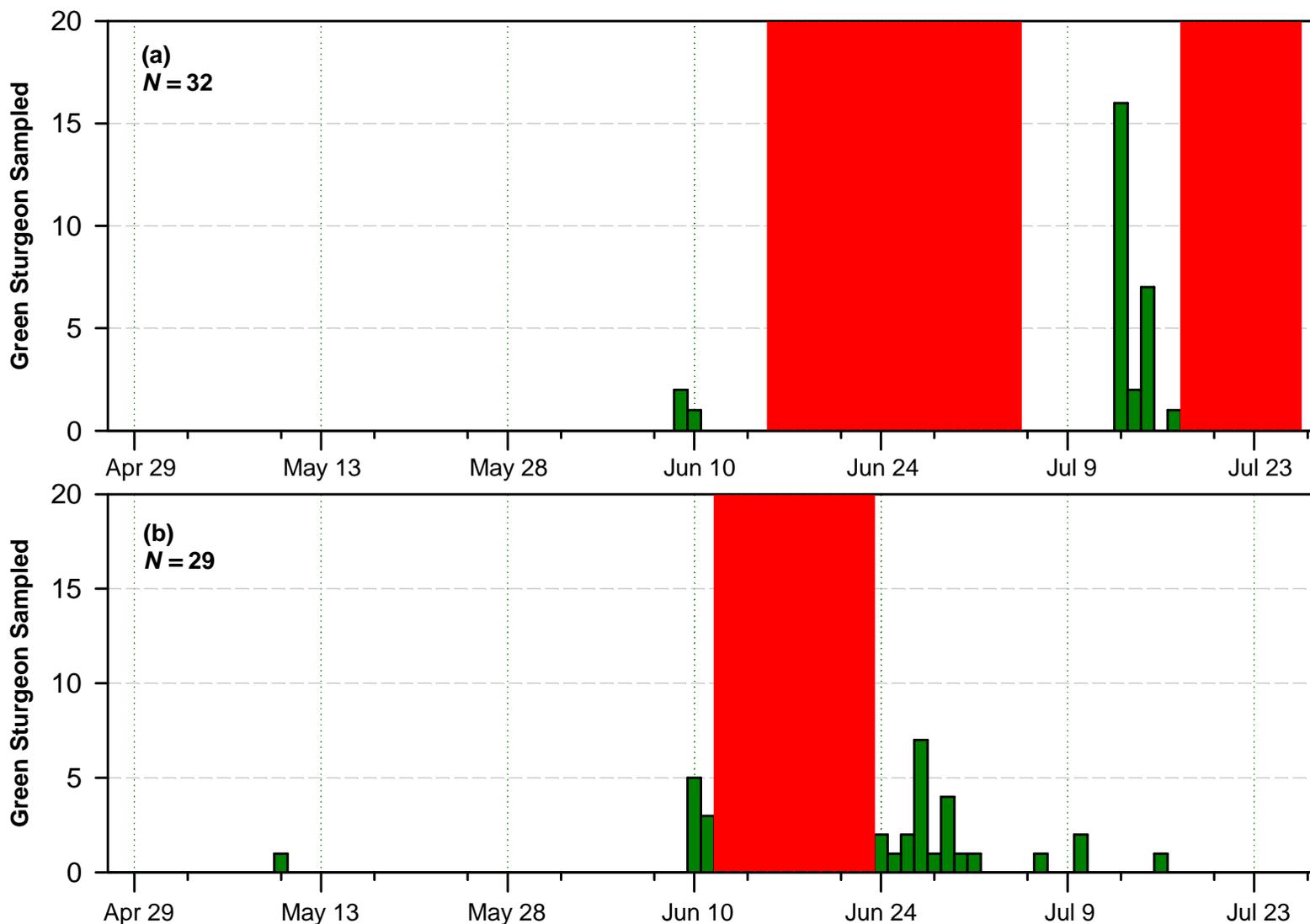


Figure 13. Green sturgeon larvae sampled by (a) benthic D-net and (b) rotary screw traps at RBDD for the period April 29 through July 27, 2009. Sampling occurred (a) at the RBDD Bypass Outfall alternating nights, typically Monday through Friday of each week and (b) directly below RBDD 7 days per week. Red blocks indicate periods sampling was not conducted (a) due to equipment failures and (b) operations associated with the lowering of RBDD gates to fill Lake Red Bluff.

2009 Sample Gear Catch Comparisons

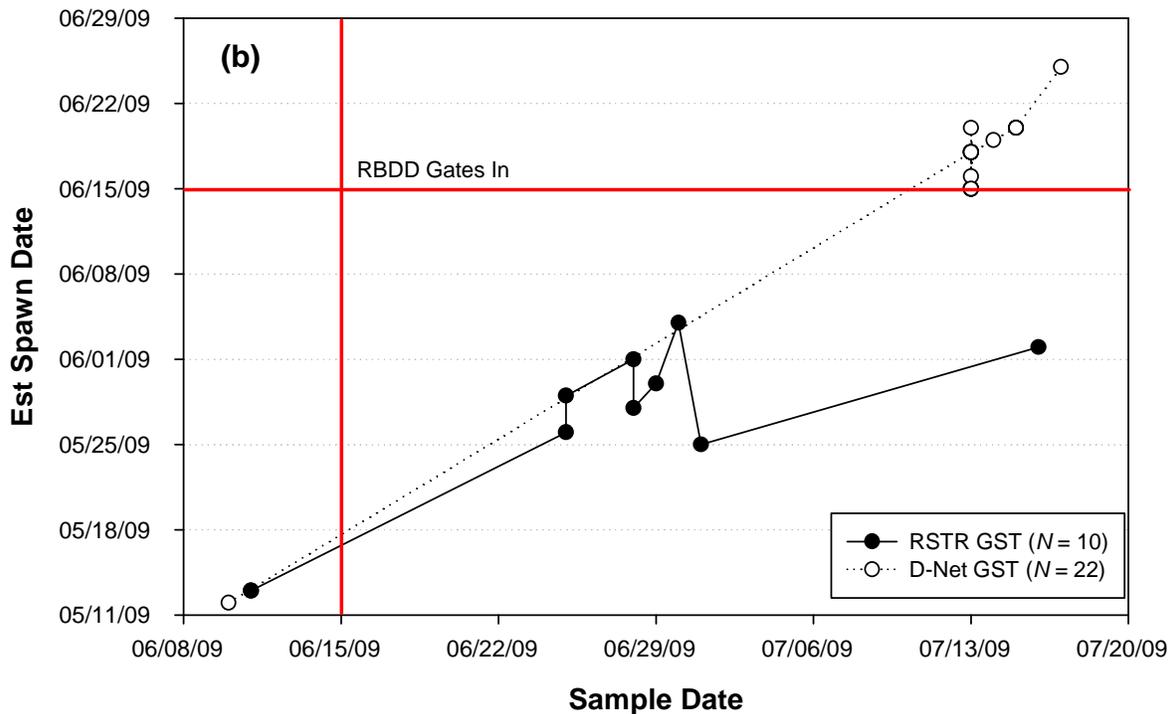
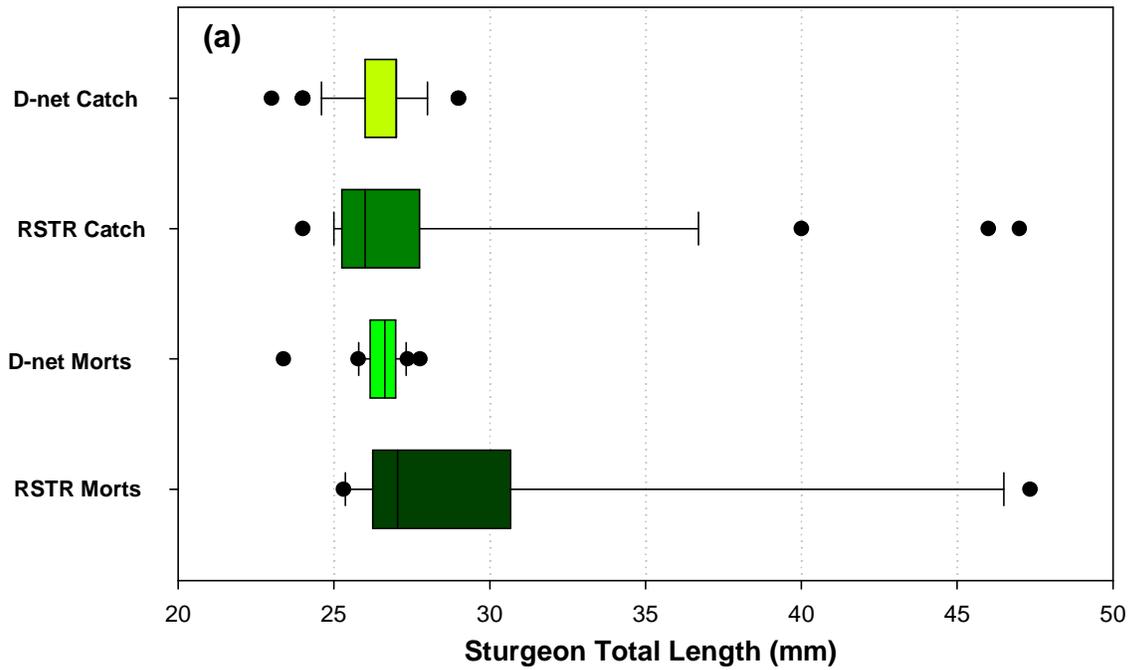


Figure 14. Comparisons of sturgeon larvae catch results from benthic D-net (targeted sampling) and rotary screw traps (non-targeted sampling) at RBDD. Figures indicate (a) length comparisons of sturgeon sampled and (b) estimated spawn dates (morts only) in relation to sample dates using the two sample gear types.

2009 Hourly Larval Sturgeon Catch Distribution

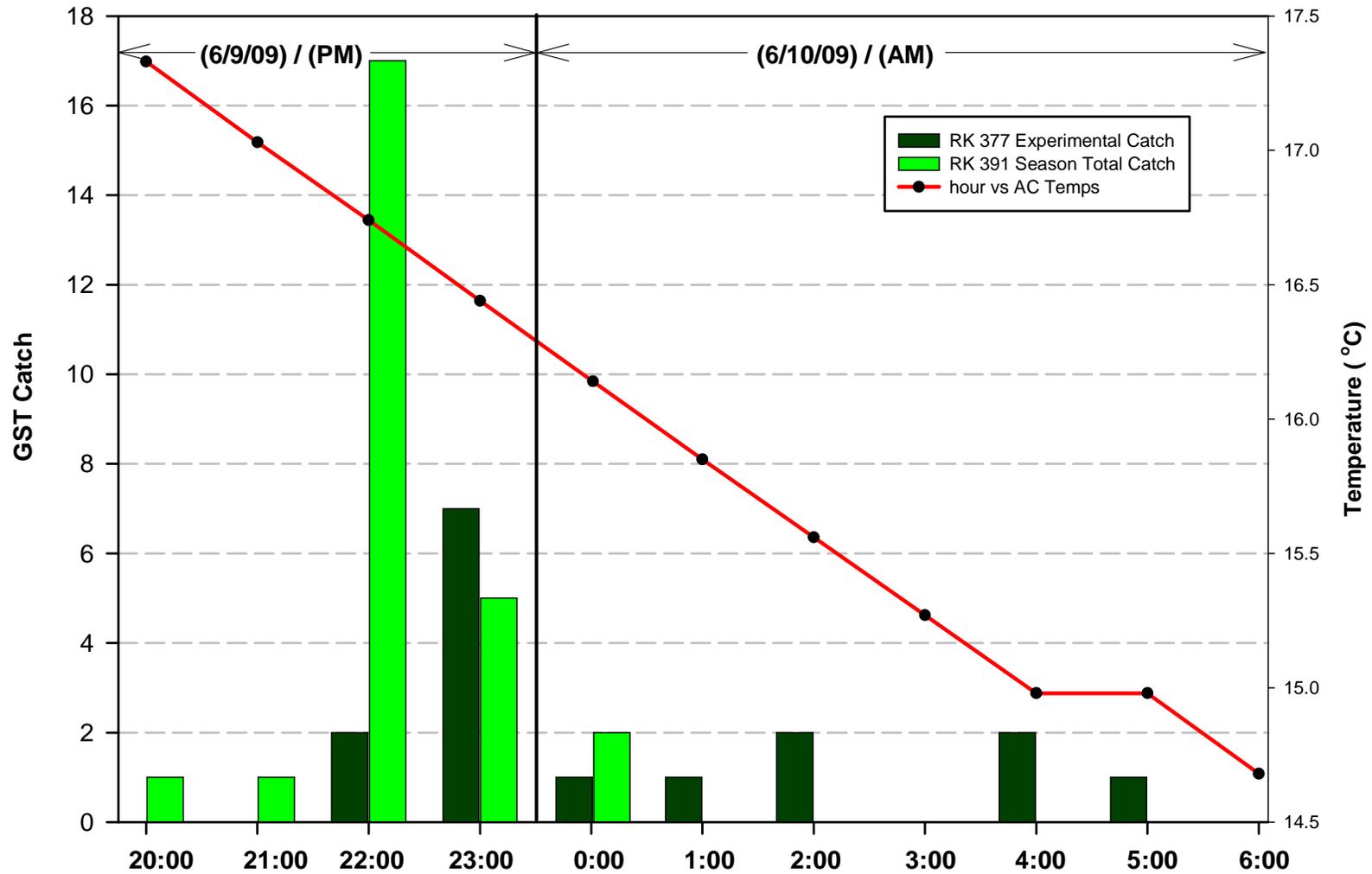


Figure 15. Nocturnal distribution pattern comparison for cumulative season total (light bars) of green sturgeon captures versus catch pattern detected at RK 377 (dark bars) on the night of June 9 to the morning of June 10, 2009. Water temperature associated with overnight sampling included showing trend throughout overnight sample period (red line).