2008 UPPER SACRAMENTO RIVER GREEN STURGEON SPAWNING HABITAT AND LARVAL MIGRATION SURVEYS

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Prepared by:

William R. Poytress[1]
Joshua J. Gruber[1]
David A. Trachtenbarg[1]
And
Joel Van Eenennaam[2]

[1]U.S. Fish and Wildlife Service
Red Bluff Fish and Wildlife Office
10950 Tyler Road
Red Bluff, CA 96080

[2]University of California Davis
Department of Animal Science
One Shields Avenue
Davis, CA 95616-8521

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2008 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys

William R. Poytress, Joshua J. Gruber, and David A. Trachtenbarg

U.S. Fish and Wildlife Service, Red Bluff Fish and Wildlife Office,
10950 Tyler Road, Red Bluff, California 96080, USA

Joel P. Van Eenennaam

Department of Animal Science, University of California,
One Shields Avenue, Davis, California 95616-8521, USA

Abstract.— Three spawning sites of Southern Distinct Population Segment green sturgeon, *Acipenser medirostris,* were confirmed in the upper Sacramento River, California in 2008. Forty-two positively identified eggs were sampled by artificial substrate mats with placement guided by use of real-time acoustic telemetry data. Spawning events were estimated to have occurred several river kilometers upstream and downstream of the Red Bluff Diversion Dam (RBDD) prior to, and subsequent to, the May 15 seasonal dam gate closure. Spawning was estimated to have occurred directly below RBDD more than a month after the gate closure. The temporal distribution pattern suggested by this first of three year study indicates spawning of green sturgeon occurs from April through July. Egg samples were collected in distinct microhabitats from two natural sample sites at water depths ranging from 2.9 to 7.6 m ($\bar{x}$ = 4.5 m), whereas a single egg sampled directly below RBDD was sampled at a depth of 0.6 m. Sacramento River flows and temperatures ranged from 240.7 to 352.3 m^3s^{-1} ($\bar{x}$ = 293.1 m^3s^{-1}) and 10.1 to 17.6°C ($\bar{x}$ = 13.9°C) during the estimated spawning period. Qualitative substrate surveys using an underwater video camera and direct observation consistently indicated medium sized gravel as the dominate substrate material green sturgeon eggs were sampled from. Sampling for drifting larvae using a benthic D-net proved minimally successful with a total catch of four green sturgeons between June 17 and July 15. All larvae were sampled from the solitary mid-channel habitat site directly below RBDD. Two sample sites upstream and two further downstream of the RBDD resulted in a catch of zero green sturgeon larvae. Limited rainfall and low spring discharge in 2008 was hypothesized as resulting in a low density of spawning adults and subsequently low production of recruits which has been noted in other river systems supporting a variety of sturgeon species.

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Introduction

The Sacramento River in Northern California currently hosts the only known spawning population of Southern Distinct Population Segment (SDPS) green sturgeon, *Acipenser medirostris* (BRT 2005). This genetically distinct population (Israel et al. 2004) was listed as threatened under the Federal Endangered Species Act on April 7, 2006 (NMFS 2006). As a result, a greater level of concern by the US 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 species may be affected by current operations of RBDD. In 2008, the USBR and the University of California, Davis (UCD) conducted research and monitoring on the adult life history phase of green sturgeon (see Israel et al 2009; R. Corwin, USBR, unpublished data). The US 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.

The USFWS (Brown 2007) found sparse evidence of green sturgeon spawning below and above RBDD by sampling eggs and larvae, respectively. Larval and juvenile green sturgeon have been captured from the upper Sacramento River by the rotary-screw traps placed directly below RBDD since 1995 (Johnson and Martin 1997; Gaines and Martin 2002). Based on these captures, it was assumed spawning occurred above RBDD as opposed to directly in front of rotary-screw traps on the downstream side of the dam. Capture of green sturgeon larvae prior to the annual lowering of the RBDD gates on May 15 of each year (NMFS 2004) supports this assumption (Gaines and Martin 2002; Poytress 2006). Furthermore, eight 2-year old juvenile green sturgeon were recovered at the RBDD east diffuser during maintenance operations by USFWS in the early 1990's (USFWS 1992).

Objectives

The objectives of this study were to: (1) evaluate the use of three varieties of egg sampling devices, (2) determine the temporal and spatial distribution of spawning (via egg deposition) by green sturgeon in close proximity to RBDD, (3) monitor the environmental conditions of the sites where eggs were found by describing microhabitats 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, and (5) determine if distinct nocturnal patterns of migration occurred in pre- and post exogenous feeding larvae.

This annual report addresses, in detail, egg and larval sampling of green sturgeon for the period April 22 through August 15, 2008. This report includes data and information on green sturgeon spawning areas and limited qualitative spawning substrate surveys from multiple upper Sacramento River sites in close proximity to 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 60 river kilometer reach of the Sacramento River from Jelly's Ferry Bridge (RK 429) to Tehama Bridge (RK 369) with RBDD roughly 1/3 of the way in between (Figure 1). The study area was determined to contain likely spawning habitat with known annual green sturgeon presence based on USFWS and USBR personal observations coupled with recent acoustic telemetry data (Hublein et al. 2006; R. Corwin, USBR, pers. comm.). The primary focus of the study was to assess potential impacts of RBDD operations on green sturgeon and the study area, as described, provided logistically feasible sampling locations both upstream, at, 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 (Figure 1) based on visual observations, side scan sonar, and acoustic telemetry data (R. Corwin, USBR, pers. comm.). 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). The orientation of the furnace filter material allowed either side of the egg mat to collect eggs. Egg mats were held in position by a three-fluke cement-filled poly-vinyl chloride (PVC) anchor attached to the upstream end of the egg mat using two 76 cm pieces of 6.4 mm diameter aircraft cable. 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.

In an attempt to improve on the methods used by Brown (2007), two experimental egg samplers were developed and deployed. A 3D design (i.e., egg tube; see Firehammer et al. 2006) was constructed by the USBR by cutting 40 cm lengths of 25.4 cm diameter PVC pipe. Three lengths of pipe were laid flat and bolted together in a 2x1 pyramid formation. Filter material was glued to the inside and outside surfaces of the pipe using a construction adhesive. To prevent eggs from potentially passing through the tubes, the downstream end of each tube was covered with filter material. Finally, the pyramid was secured to the rear portion of a standard egg mat using 6.4 mm plastic coated aircraft cable (Figure 2b). The purpose of the egg tube design was to capture green sturgeon eggs that may be drifting within the bottom 0.6 m of the water column.

The second experimental egg sampler design (i.e., egg roll) attempted to increase catch by increasing the total surface area of the sampler. Three meters of filter material were zip-tied to 6.4 mm plastic mesh. For structure and weight, a 3.0 m x 0.6 m frame was constructed out of 9.5 mm chain and rebar. All three layers were zip-tied together so they could be rolled out perpendicular to the water flow (Figure 2c). The single layer of filter material, presumably, could only collect eggs on the topside of the sampler.

Paired egg mats were placed in three microhabitat types at two natural locations on the Sacramento River commonly known as Massacre Flats (RK 424.5) and the mouth of Antelope Creek (RK 377). The three microhabitat types were described as *upstream* (riffle entering the pool), *within pool* (flanking the deepest portions of the pool), and *tail* (glide exiting the pool upstream of the pool tail crest).

Up to three sets of paired samplers were placed in an unnatural setting directly below RBDD (RK 391) following the annual, seasonal gate lowering which typically occurs in mid-May of each year. As noted in Brown (2007), green sturgeon annually assemble below the dam following the gate closure and evidence of spawning has been confirmed. Egg mats and experimental samplers were deployed below the dam downstream of observed sturgeon aggregations. Sampling locations varied but were placed initially as close to boils as physically possible since sturgeon were observed moving in and out of these very turbulent areas.

Mats were visually inspected twice a week throughout the sample period, typically on Tuesdays and Fridays. Paired egg mats from each microhabitat were pulled from the river, placed on the deck of a boat, and inspected 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 collected in a plastic tote and filtered through 3.2 mm mesh netting placed over a five gallon bucket to capture dislodged eggs. After a second inspection, egg mats were redeployed into their respective microhabitats.

Environmental and sample effort data was collected during both the setting and retrieval of the substrate samplers. Environmental data consisted of: GPS coordinates recorded between the paired mats' floats, river flow, turbidity, sample depth, weather condition, and moon phase. Hourly water temperature was monitored at or near each site using a Stowaway® Tidbit temperature logger. Sacramento River hourly flow data was obtained from the California Data Exchange Center's Bend Bridge gauging station (http://cdec.water.ca.gov/cgi-progs/queryF?BND).

Flows below RBDD and at the mouth of Antelope Creek were estimated by using Bend Bridge data subtracting daily diversions at RBDD (when applicable). Sample effort data consisted of: date and time egg samplers were set and retrieved and designation of samplers in relation to each other (i.e., river left or right) within each microhabitat. When visually possible, it was noted whether egg mats were sampling top or bottom side up.

Egg samples were counted and identified to species for each egg mat in the field. All suspected green sturgeon and unidentified eggs were collected into vials of 95% ethyl alcohol (EtOH) for laboratory identification 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 identification, photography, measurement of egg diameter, and determination of developmental stage (Dettlaff et al. 1993). Moreover, spawn date was estimated based upon egg collection date and developmental stage and was back-calculated using average daily water temperature from the nearest Sacramento River gauging station (Wang et al. 1985; 1987; Deng et al. 2002). Non-green sturgeon eggs were identified 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 composition surveys of green sturgeon deep water spawning habitat were tested (i.e., pilot effort) and performed in a limited capacity using underwater videography. This technique has been performed in large, deep mainstem rivers focusing on deep water spawning habitat of fall Chinook salmon (*Oncorhynchus tshawytscha*), but also for lake trout (*Salvelinus namaycush*), as well as bottom dwelling burbot (*Lota lota*; Groves and Chandler 1999). Deep water habitat surveys were performed using a Speco CVC 620 WP 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 used to suspend the camera setup from the bow of a boat using two 11 kg sounding weights (Groves and Garcia 1998) added for stability in fast moving water environments (Figure 3). A 12 volt ATV winch was used to raise and lower the camera/carrier in the water column during deployment. Video images were recorded on a 4 channel MPEG-4 networkable DVR and displayed in real-time on an 18 cm LCD monitor.

Surveys performed with the underwater video camera (UVC) typically proceeded from the furthest point downstream to the upstream end of known sturgeon holding pools, based on the presence of acoustically tagged adults. The UVC (facing upstream) was lowered in the water column near the pool tail crest until substrate was clearly visible on the LCD monitor. Surveys progressed slowly upstream (1- 2 km/hr) through the holding pool microhabitats with the UVC raised and lowered to keep within 30 cm of the river bottom. At the end of each reach the UVC was raised to the water surface or secured onboard within the deployment apparatus. Generally, each reach was surveyed multiple times with observation data including approximate location, time, substrate, depth, and notable underwater and above water physical features recorded for later reference. Substrate was visually estimated using substrate descriptors listed in Dunne and Leopold (1978). Substrates were described as sand (<2.0 mm), gravel (2.0 to 64.0 mm), cobble (64.0 to 256.0 mm), and boulder (>256.0 mm). Recorded video was later played through a Honeywell Fusion DVR and re-recorded to provide more playback and software editing features. Short video segments were then re-saved and labeled to designate specific microhabitat areas within each site.

Larval migration surveys.**—** Larval drift sampling was scheduled to occur from mid-May through mid-August based on suspected outmigration timing (Gaines and Martin 2002; Van Eenennaam et al. 2001; Brown 2007). Successful egg capture during the concurrent USFWS egg mat sampling aided in refining the exact start and end dates. Based on previous studies on the Sacramento River (Brown 2007; USFWS unpublished data) and laboratory studies (Van Eenennaam et al. 2001; Kynard et al. 2005) indicating nighttime migration activity, larval sampling typically occurred between the hours of 22:00 and 05:00.

A benthic D-net was used throughout the season, similar to previous nets used for larval sturgeon sampling on 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.

Stratified night sampling occurred two days per week at four sample sites (Figure1); Jelly's Ferry Bridge (RK 429), Bend Bridge (RK 415), RBDD Bypass Outfall (RK391), and Tehama Bridge (RK 369). Sites were selected for their proximity to suspected spawning locations over a 60 km stretch centered on RBDD, ease of accessibility at night, and the presence of adequate tie-off structures (e.g., bridge supports) in a variety of 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 and Tehama Bridge were selected as the next nearest upstream and downstream sampling locations, respectively, to meet the sampling criteria objectives. A 4-week rotational sampling matrix (Table 1) was used to spatially and temporarily distribute stratified sampling effort evenly between the sites. The RBDD Bypass Outfall and Tehama Bridge were sampled below the RBDD diversion dam on Tuesdays while Jelly's Ferry Bridge and Bend Bridge were sampled above RBDD on Thursday nights.

In addition to the stratified Tuesday/Thursday sampling, exploratory sampling was conducted on Wednesday nights to explore alternative sampling strategies and migration periods. Exploratory sampling occurred at Woodson Bridge (RK 352) and Tehama Bridge (RK 369). Additionally, exploratory sampling at the RBDD Bypass Outfall (RK 391) consisted of prolonged sampling (e.g., 4-6 hours) and sampling to determine if possible crepuscular movement patterns existed (i.e., matutinal and vespertine periods).

Nightly sampling effort typically consisted of a total of 240 minutes of wetted net time. During stratified sampling, nightly effort was split into two 120 minute sample periods per site. During exploratory sampling, effort was concentrated at a single site. 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. Tehama Bridge consisted of four potential tie-off locations. Two tie-off locations near the thalweg were selected for the stratified sample periods while all four were used for exploratory sampling. During stratified and exploratory sampling, the net was generally set to sample for 30 or 60 minute sets depending on debris accumulation and fish occurrence.

Effort and environmental data collected for each sample site included set and retrieve times, estimated tie-off distance, turbidity, surface water temperature, and water depth at the stern of the boat. 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 and eggs were retained in 95% EtOH for genetic identification (Israel et al. 2004) and developmental stage assessment (Dettlaff et al. 1993). Non-sturgeon eggs and larvae samples were visually identified or confirmed to the species level by Rene Reyes and Dr. Johnson Wang of the US Bureau of Reclamation's Tracy Fish Salvage Facility.

Results

***Egg Sampling surveys*.—** Egg mat sampling occurred at the two natural sites (RK 424.5 and RK 377) between April 22 and August 1, 2008. Egg mats were deployed at RBDD on May 29, 2008, once sturgeon aggregations were observed following the lowering of the dam gates on May 15, 2008. Egg mats sampled a total of 1201.58 wetted mat days (one mat set 24 hours; Table 2). Both experimental egg samplers were removed shortly after deployment (i.e., egg roll = 0.99 wetted mat day; 3D egg tube = 15.87 wetted mat days) due to the difficulties associated with setting, retrieval, or inspection. Three mats were lost over the course of the sampling season. On various occasions upstream and tail mats were found downstream from their original deployment location, possibly due to high flow velocities or interactions with the public. On July 3, 2008 sampling of half of the mats at RBDD and the upstream mats at both natural locations was discontinued. It appeared that spawning activity had concluded below RBDD based on the downstream movement of acoustic tagged adult green sturgeon and lack of visual observations of aggregating sturgeon (R. Corwin and R. Chase, USBR, pers. comm.). Due to the downstream proximity to suspected spawning grounds, tail mats were left in the river for an additional two weeks. On July 15 (RK 424.5) and July 18, 2008 (RK 377) the tail mats were removed along with the remaining mats at RBDD. On August 1, 2008 within pool mats were removed from the river.

Between May 2 and July 7, 2008 forty-two eggs were sampled by egg mats and positively identified as green sturgeon (Figure 5). Positively identified egg samples were collected primarily in the *within pool* microhabitats at RK 424.5 (N =11) and RK 377 (N = 30). One green sturgeon egg was collected from the unnatural site directly below RBDD. Based upon 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 12 different females who spawned between April 30 and July 4, 2008 (Table 3). On two occasions it was estimated that multiple spawning events (i.e., eggs from different females) were captured during one sampling period on a single egg mat. Genetic analysis performed by Dr. Josh Israel was unable to determine the actual number of spawning events (Israel et al. 2009).

Egg mats sampled at water depths ranging from 0.5 to 7.6 m and depths were comparable within microhabitat types between the two natural sites (Table 4). Sample depth ranged from 2.9 to 7.6 m ($\bar{x}$ = 4.5 m) for eggs collected in the natural habitats (Figure 6). The egg found directly below RBDD was collected at a depth of 0.6 m (Figure 6).

Green sturgeon eggs were found adhered to the top (N = 17) and bottom (N = 21) of the egg mats, as well as in the rinse water (N = 4). On four occasions eggs were found on both sides of the same egg mat. During one mat sampling event, eggs were found in all three areas (i.e., top, bottom, and rinse). Moreover, green sturgeon eggs were notably adhesive as many were found to have variable sized grains of sand adhered to the jelly coat (Figure 7); some adhered directly to the steel framework of the mats. Egg diameter was possible to measure on 88% of the green sturgeon eggs sampled and ranged from 3.75 to 4.67 mm ($\bar{x}$ = 4.12 mm; N = 37).

Limited rainfall (0.66 cm) during the sample period did not appreciably affect Sacramento River flow or turbidity. Sacramento River flows during the sample period ranged between 220.0 to 393.6 m^3s^{-1} at Bend Bridge (Figure 8) and 278.2 and 353.6 m^3s^{-1} at RBDD (Figure 9). Flows increased over the sample period due to Shasta/Keswick Dam releases during the primary agricultural irrigation season. On May 15, 2008 flow was substantially increased temporarily to facilitate the filling of Lake Red Bluff following the lowering of the RBDD gates.

Sacramento River flows ranged from 240.7 to 322.8 m^3s^{-1} ($\bar{x}$ = 267.8 m^3s^{-1}) at Bend Bridge and 252.7 to 352.3 m^3s^{-1} ($\bar{x}$ = 286.8 m^3s^{-1}) at RBDD during the period when green sturgeon eggs were collected at RK 424.5 (Figure 8) and RK 377 (Figure 10), respectively. Flows ranged from 297.5 to 338.4 m^3s^{-1} ($\bar{x}$ = 324.7 m^3s^{-1}) during the sample period when the green sturgeon egg was collected at RBDD (Figure 9).

Turbidity ranged from 0.8 to 3.7 nephalometric turbidity units (NTU) throughout the sample period ($\bar{x}$ = 2.2 NTU). During the estimated spawning period, turbidity ranged from 1.7 to 3.1 NTU ($\bar{x}$ = 2.5 NTU). Water temperatures ranged from 9.2 to 16.3°C ($\bar{x}$ = 13.3°C) at Bend Bridge, 13.1 to 16.3°C ($\bar{x}$ = 14.9°C) at RBDD, and 10.1 to 17.6°C ($\bar{x}$ = 14.8°C) below the mouth of Antelope Creek during the sampling period. During the estimated spawning periods water temperatures ranged from 10.1 to 15.2°C ($\bar{x}$ = 12.4°C) at RK 424.5 (Figure 8), 14.3 to 15.4°C ($\bar{x}$ = 14.9°C) at RK 391 (Figure 9), and 12.9 to 17.6°C ($\bar{x}$ = 14.3°C) at RK 377 (Figure 10).

***Spawning substrate surveys*.—** UVC spawning habitat surveys were conducted at the egg sampling locations at RK 424.5 and RK 377 on May 5, 2008. Water depths ranged from 1.0 to 15.2 m and 1.0 to 12.2 m, respectively. Sacramento River discharge was 312 m^3s^{-1} (above RBDD) and 305 m^3s^{-1} (below RBDD). UVC surveys of the within pool habitat at RK 377 recorded green sturgeon in depths >6.5m.

UVC spawning habitat surveys confirmed the general substrate within each microhabitat type sampled by egg mats. At RK 424.5 and RK 377, upstream mats were placed primarily on a cobble substrate interspersed with gravel. Moreover, large cobble and boulders appeared to be embedded sporadically in the river bottom at RK 424.5. The within pool microhabitat at RK 424.5 where confirmed green sturgeon eggs were sampled had a substrate consisting of medium sized gravel with lesser amounts of cobble and sand. The within pool microhabitat at RK 377 where confirmed green sturgeon eggs were sampled also contained predominantly medium sized gravel. Large boulders were evident in the deepest and most turbulent water of both sites' deepest within pool microhabitats. Interestingly, both sites had large river right areas of sand deposited parallel to heavy hydraulics associated with large boulders. The tail mats at both locations were placed in small to medium gravel and small cobble substrates interspersed with small pockets of sand.

UVC surveys could not be effectively performed at RBDD due to shallow water conditions, poor visibility, and safety concerns in the area of the hydraulics directly below the lowered dam gates. However, visual observations could be made at the shallow areas flanking the hydraulics where the single green sturgeon egg was found. Observations noted substrate composed of medium sized gravel mixed with sand as the dominant materials found in this area. In the turbulent high velocity areas close to the base of the dam, large boulders and rip rap are present which were placed after the construction of RBDD to prevent erosion of the dam's apron.

***Larval migration surveys*.—** Larval drift sampling occurred from May 27 to August 15, 2008. Wetted net time totaled 100 hours (6,000 minutes) during stratified sampling efforts on Tuesdays and Thursdays (Table 5). A total of 35.6 hours of wetted net time were sampled during exploratory efforts on Wednesdays (Table 6). Sampling at Woodson Bridge (RK 352) was discontinued after a single night due to submerged objects entangling the net. All other sites were sampled effectively.

As noted in the egg sampling results section of this report, no major rain or flow events occurred during the sampling season and Sacramento River conditions were primarily the result of water releases from Shasta/Keswick Dam (Figure 8). Turbidity values derived from surface grab samples were relatively stable throughout the season and ranged from 1.3 to 4.3 NTU ($\bar{x}$ = 2.0 NTU). Debris loads from collected samples were generally light to moderate, typically consisting of leaves and aquatic vegetation.

River depth data was recorded at the stern of the boat for each sample. Depth data was variably representative of actual sample collection depths as the net typically sampled from 0.6 to 46.0 m ($\bar{x}$ = 16.2 m) downstream of the boat. Overall, estimated sample depths ranged from 2.5 to 23.4 m (Table 7).

A total of four positively identified green sturgeon larvae were captured during the 2008 sampling season. All samples were collected from the RBDD Bypass Outfall (RK 391). Three larvae were captured between 22:05 on June 17 and 00:09 on June 18, 2008 at a water temperature of 14.9° C. A single larvae was captured between 22:48 and 23:54 on July 15, 2008 at a water temperature of 15.3° C. Total length of larvae sampled ranged from 24 to 26 mm ($\bar{x}$ = 25 mm). All four larvae were determined to be at developmental stage 45 indicated by complete yolk sac absorption using Dettlaff et al. (1993). Estimated spawn dates for the three samples and single sample were May 28 to 30 and June 25 to 27, 2008, respectively (Table 8). In addition to the four sturgeon larvae, a variety of non-target species eggs and larvae were sampled and enumerated (Table A1).

Discussion and Recommendations

***Egg sampling surveys*.—**Through the sampling and positive identification of green sturgeon eggs using artificial substrate mats, three spawning areas in the Sacramento River were confirmed in 2008. Green sturgeon eggs were sampled on multiple occasions exclusively at the within pool microhabitat at the two natural sites (RK 424.5 and RK 377). Eggs were first sampled from the within pool microhabitat 33.5 river kilometers above the RBDD thirteen days before the lowering of the RBDD gates which creates a barrier to upstream migrating sturgeon (Brown 2007). Green sturgeon eggs were sampled within ten days of initial egg mat deployment and likely should have been deployed sooner as acoustic tagged fish were detected in the upper Sacramento River in late March and passed upstream of the RBDD on April 14, 2008 (R. Corwin, USBR, pers. comm.). Limited acoustic telemetry data was available to fine tune sampling efforts at the uppermost sample site (RK 424.5). A total of 11 green sturgeon eggs were sampled from this site from May 2 to June 13, 2008 indicating spawning occurred before and after RBDD gates were lowered on May 15, 2008 (Figure 5). The estimated spawning dates of the eggs sampled above RBDD ranged from April 30 to June 10, 2008 and indicated at least three different spawning dates or events within a six week period at this site (Table 3).

The majority of green sturgeon eggs (71%) were sampled at RK 377, 14 river kilometers below the RBDD. Ten green sturgeon adults were acoustically tagged before and after the lowering of the dam gates at this site (R. Corwin, USBR, pers. comm..) and monitored using stationary and mobile acoustic receivers (M. Thomas, UCD, pers. comm.). Weekly mobile tracking and continuous shipboard tracking of one tagged adult (M. Thomas et al., UCD, unpublished data) appeared to indicate a repeated, sustained holding pattern near the deepest portion of the pool (>7m). Paired within pool egg mats were placed flanking this deep holding area. Within a week, green sturgeon eggs were sampled from this microhabitat indicating spawning was occurring within the pool, presumably a short distance upstream of the samplers. Interestingly, the first green sturgeon egg samples derived from this site appeared to be from two different spawning events (Table 3). One spawning event preceding sampling by a few hours and one estimated to have occurred the day prior to sampling; assuming the first female completed egg oviposition within 24 hours.

Green sturgeon eggs were first sampled 13 days prior to the lowering of the RBDD gates and samples were collected nearly weekly for an eight week period (Figure 5). Egg analysis estimated spawning was occurring from April 30 to July 4, 2008. Of particular interest is that spawning was confirmed downstream of the RBDD prior to the lowering of the dam gates from an estimated 3 to 4 different events (Table 3) indicating habitat specific preference associated with this site or possible spawning site fidelity. As noted by Erickson and Webb (2007), green sturgeon tagged in the Rogue River, Oregon return after 2 to 4 years; fidelity for spawning sites in the Sacramento River may provide further evidence of this behavior.

One green sturgeon egg was sampled below Gate 8 at the RBDD on June 20, 2008. Spawn date for this egg was estimated to be June 19, 2008; 34 days after the lowering of the RBDD gates in mid-May. Sampling at the RBDD site was inherently more difficult because hydraulics created by the lowered dam gates tended to displace sand and gravel which often partially or completely buried the egg mats within 3 to 4 days. Mats were placed further downstream of the hydraulics in shallower areas (i.e., gravel bar directly below hydraulics) later in the sampling season to avoid the sustained heavy loading of sand and gravel and because of a lack of egg samples. It was at one of the downstream sampling areas at RBDD that the green sturgeon egg was sampled. Sampling of the single egg at this site may have simply been the result of sampling the mat within 24 hours of spawning and the fact that the egg was "nestled" in the furnace filter material. Evidence of sustained sand and gravel aggradation immediately below the dam contrasted greatly to the conditions at the natural sites where within pool mats typically had minimal sand or gravel deposits. The amount of fine material displaced daily and the evidence of spawning directly below RBDD causes some concern as it relates to incubation and hatching success of eggs deposited immediately below the dam's hydraulics. The aggradation of sand and gravel could result in partial or complete burying of green sturgeon eggs resulting in delayed hatching time, physiological effects, or mortality as was observed in the laboratory for white sturgeon, *Acipenser transmontanus*, by Kock et al. (2006).

Recommendation*: Employ in-river channel level gauges in multiple areas below the dam's hydraulics to determine the temporal and spatial patterns of river channel aggradation or degradation resultant from RBDD gates lowered operations.*

The green sturgeon egg sampled at RBDD was found at a water depth of 0.6 m which was nearly 4 meters shallower than the average depth eggs were sampled at the two natural sites. Moreover, it should be noted that the depths recorded at the within pool microhabitats of the natural sites were likely between 0.5 - 1.0 m deeper than actual mat depths due to the location of the depth finder transducer which was 2 meters behind the actual mat retrieval location. The result was likely a conservative (i.e., shallow) reading compared to the actual depth of the mats. Furthermore, spawning was presumably occurring slightly upstream of the mats which would be deeper given the general up sloping shape of the pools.

Recommendation*: Employ more advanced depth sounding equipment and methodologies to increase the accuracy of egg sample collection depth readings.*

The use of artificial substrate mats proved reasonably effective at sampling green sturgeon eggs. As noted earlier, the eggs are adhesive, albeit for a short period of time. The detection of eggs in the rinse water indicated that sample processing may have dislodged eggs that were not embedded in the filter material or largely adhered to the mats. The result was likely a reduction in detected egg samples during the retrieval process or during mat arrangement onboard the sampling vessel. Moreover, algae and sand entrained within the filter material may have reduced the ability of eggs to adhere to egg mats or resulted in the dislodging of eggs during processing as sand and debris were often flushed from the mats during retrieval.

Recommendation*: Carefully retrieve all egg mats during sample collection activities and store them in a catch basin that allows draining water and debris to be captured, filtered, and inspected for easily dislodged eggs.*

Overall, the egg mat sample design employed in 2008 at the natural sites was successful in collecting green sturgeon eggs at possible spawning areas in close proximity to known holding areas. Prior to this years egg collections, it was unknown if green sturgeon were moving upstream from the deep pool holding areas, staying within the pools, or dropping downstream towards the pool tail crest to spawn. Repeated capture of eggs from the areas flanking the deepest portions of the pools would indicate spawning is occurring at or near the deepest portions of the pools. Presumably, demersal green sturgeon eggs adhere to areas on the upslope of the pool several meters upstream of the pool tail crest.

At both natural sites, complex hydraulics formed by water flowing at sharp river bends (at the confluence of a tributary in one case) into deep pools containing large boulders resulted in surface turbulence and complex hydraulics at, and immediately downstream of, the deepest portions of the pool. These areas when sampled with egg mats resulted in capture of green sturgeon eggs and would appear to be important components of green sturgeon spawning habitat; similar to the findings of Zhang et al. (in press) hypothesized bedform morphology for Chinese sturgeon, *Acipenser sinesis*, in the Yangtze River, China. Additionally, spawning habitat of white sturgeon, *A. transmontanus*, in the Fraser River, Canada was noted by Perrin et al. (2003) to occur in similarly complex hydraulic areas at river confluences (although not exclusively) which compares remarkably with the site eggs were sampled at the mouth of Antelope Creek (RK 377).

Recommendation*: Perform egg sampling in remaining study years at the within pool habitat and discontinue sampling the upstream and tail portions of the same two sites. Additionally, sample additional presumed spawning sites guided by real-time acoustic telemetry data but sample all sites with at least two pairs of mats to determine lateral and longitudinal extent of spawning. Begin sampling for green sturgeon eggs by April 1*st *or as soon as adults are detected by acoustic receivers above Woodson Bridge (RK 352). Deploy site specific thermographs throughout the season and Hydrolabs upon sample collection to monitor hydrologic variables where green sturgeon eggs are collected.*

***Spawning substrate surveys*.—**The pilot substrate surveys using the UVC system indicated a fairly consistent substrate type of medium sized gravel in the areas where green sturgeon eggs were sampled. At both natural sites and RBDD the substrate appeared much smaller than the "likely preferred large cobble" noted in Moyle (2002). UVC and direct observation of substrate materials in the areas of the positively sampled egg mats indicated smaller substrate falling into the gravel category using the size class designation provided in Dunne and Leopold (1978). Although this year's efforts did not attempt to quantify the size of substrate materials, observations clearly indicated egg deposition onto substrate composed primarily of gravel.

Sand grains adhered to many of the green sturgeon egg samples indicating adhesiveness of the eggs (Figure 7). The gelatinous layer of the egg chorion forms an adhesive surface after exposure to water, and for green sturgeon this initially begins after the first 20-30 seconds and is more pronounced after 2-4 minutes (Van Eenennaam, unpublished data; Van Eenennaam et al. 2008). The formation of this adhesive area of attachment lasts 20-30 minutes (Markov, 1978). The sand grains could have adhered to the eggs surface after fertilization or possibly during rinsing of the egg mat which would dislodge the egg thus allowing sand from the rinse water to possibly attach to the exposed adhesive area. UVC and direct observations indicated varying degrees of sand mobility on the river bottom at all sites, albeit the least bed mobility was noted in the within pool areas.

Recommendation: *Acoustic doppler current profiling and bathymetric studies coupled with systematic geo-referenced substrate mapping of spawning areas may illuminate habitat conditions to determine if trends in substrate, velocity and depth occur. Additionally, underwater videography for sustained periods of time could potentially result in direct observation of spawning behavior, the relative position of spawning adults in the water column and in relation to complex hydraulics, and associated substrates adults directly spawn over in deep pool areas. After each egg sampling season, confirm substrate size composition where sturgeon eggs were sampled using a Ponar substrate sampler.*

On more than one occasion underwater video monitoring was performed below RBDD by California Department of Fish and Game and USFWS biologists who noted suspected sturgeon spawning activity within and in close proximity to the dam's hydraulics. Observations included subsequent movement of Sacramento sucker (*Catostomus occidentalis*) and Sacramento pikeminnow (*Ptychocheilus grandis*) presumably feeding on green sturgeon eggs deposited immediately following spawning events. Striped bass (*Morone saxatilis*) and rainbow trout (*Oncorhychus mykiss*) were noted as shadowing green sturgeon adults as well. Concern exists as 3 of 4 of these predatory species have been documented to occur in greater densities when RBDD gates are in the lowered position with striped bass in close proximity to the turbulent hydraulic areas (Tucker et al. 1993). Presumably, greater densities of benthic predators in the vicinity of the dam could negatively impact green sturgeon recruitment if abnormally high predator congregations occur during the spawn timing of green sturgeon.

Recommendation*: Research possible predation effects on green sturgeon eggs by native and non-native species at unimpeded spawning locations and RBDD.*

Larval migration surveys**.—** Limited success was achieved using a benthic D-net to sample migrating green sturgeon larvae in 2008. Sampling effort was 4-5 times that of Brown (2007) and interestingly, we sampled four times as many larvae. Unfortunately, migratory patterns could not be assessed from this year's data as the total number of samples collected was four. Three of four were green sturgeon were sampled on the same date and all were sampled from the same location (RBDD Bypass Outfall) between the hours of 22:00 and 00:00. In contrast, the single larvae sampled by Brown (2007) occurred during the predawn hours. The laboratory observations of greater activity of sturgeon larvae in the night time period (Van Eenennaam et al. 2001; Kynard et al. 2005) and migration activity 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. A limited number of hours were sampled at the pre-dusk and pre-dawn hours (Table 6), but effort was highly concentrated on the pre and post midnight time period (Table 5). Overall effort may have been minimized each night at any particular location as we attempted to sample two different sites per night once per week (Table 1) in an effort to detect a spatial and nocturnal migratory pattern.

Auer and Baker (2002) noted capture of few larvae (<10) in 1995 and 1998 which was attributed to low river levels (i.e., low water years) and reduced spawning success of lake sturgeon (*Acipenser fulvescens*). Interestingly, they sampled 97% of lake sturgeon between 22:00 and 00:00 during 1995 – 2000. It is hypothesized that conditions in 2008 (which was noted as California's driest spring of 114 years of record) resulted in limited adult migration to spawning grounds and subsequently low production of recruits. Concurrent rotary trapping activities at RBDD resulted in zero captures of green sturgeon larvae for the first time in 13 years of sampling (USFWS, unpublished data) even though the screw trapping site is immediately upstream of the RBDD Bypass Outfall. These data coupled with additional observations of low catch for other sturgeon species in low discharge years noted by other sources (Kohlhorst et al. 1991; Perrin et al. 2003) support the hypothesis of low production in 2008. Conversely, as noted in Auer and Baker (2002), the "possibility of two hatches" or more may occur and it is plausible that sampling for larvae should have commenced earlier in the season and been dictated more by the timing of first egg captures.

Sacramento River water temperature trended upwards during the season (Figures 8-10), but displayed a mean daily fluctuation ranging from 1.5 to 3.1°C ($\bar{x}$ = 2.2°C; RK424.5), 0.3 to 3.5°C ($\bar{x}$ = 1.2°C; RK 391), and 0.9 to 3.2°C ($\bar{x}$ = 2.0°C; RK 377). Average hourly water temperatures at RBDD typically decreased during the period 21:00 and 01:00 which was followed by an hourly increase from 01:00 to 06:00 (Figure 11). The 2008 larvae captures occurred exclusively during the nocturnal period when temperatures were decreasing at RBDD. Moreover, the single green sturgeon larvae captured by Brown (2007) also occurred during a period of decreasing nocturnal temperatures. Although subtle, this diel thermal fluctuation may be of significance with respect to nocturnal activity patterns of green sturgeon larvae and future years' sampling may validate or negate this observation.

Recommendation: *Increase larval sampling effort at a concentrated area beginning mid-May or within two weeks of first egg capture. Additionally, conduct exploratory sampling efforts using the same and varied methodologies (Benson et al. 2006) immediately below and in close proximity to spawning grounds to determine habitat use and drift dynamics (Braaten et al. 2008) of age-0 green sturgeon.*

Conclusions and Preliminary Management Implications

Throughout the 2008 egg and larval sampling season, no significant rain or related natural flow events influenced the study area. Upper Sacramento River temperature and flow conditions and green sturgeon spawning habitat conditions were primarily the result of water management practices through water releases from Shasta/Keswick Dam (Figure 8) and conditions relating to the impoundment and diversion of water at the Red Bluff Diversion Dam (Figure 9 and 10). As suggested earlier, the lack of spring outflow may have resulted in lower spawner densities and subsequently low recruitment in the areas we sampled. Water temperatures in the study area appeared to be primarily within the optimal range for green sturgeon eggs and larvae throughout our sample period. The egg sample site above RBDD (RK 424.5) encountered a brief period of time that may be considered thermally sub-optimal for hatchlings at the lowest temperatures (≤ 11°C; Mayfield and Cech 2004), whereas the opposite sub-optimal range was noted during brief periods for eggs incubating downstream of RBDD at RK 377 (≥ 17°C; Van Eenennaam et al. 2005). This suggests only a 50 kilometer section of the Sacramento River contained temperatures that were optimal throughout the currently known spawning and incubation periods. Considering the lack of rain and runoff in the spring time period, it would appear that in 2008 the area in the vicinity of RBDD is *thermally* appropriate for spawning, incubation and hatching. Research of spawning habitat conditions below Tehama Bridge to Hamilton City where green sturgeon are known to aggregate (Vogel 2008; M. Thomas, UCD, pers. comm.) needs to be conducted. Furthermore, spawning of green sturgeon in the Hamilton City area needs to be determined since downstream warming of river water temperatures coupled with increased late spring and early summer water diversions in this area could constrain the riverscape available for spawning and the earliest green sturgeon life stages. The extent and duration of the warming and it's associated effects on spawners, eggs, larvae, and juveniles needs to be documented and analyzed to determine the potential impacts to this ESA listed species.

Korschgen (2007) noted that multiple sturgeon species spawning habitats have been associated in areas "below or in close proximity to impoundments or other structures that modify hydrologic characteristics or serve as migration barriers". RBDD's location and current timing of operations undoubtedly falls into this category with respect to green sturgeon. Concerns beyond sporadic direct impacts of RBDD to this species (e.g., 2007 adult mortality event; NMFS 2008) include the effects of dam operations on the reproductive success of green sturgeon. It has been confirmed that spawning is occurring before and after the May 15 gate closure upstream, directly below, and downstream of the dam. Acoustic telemetry data from 2008 indicated a behavioral characteristic of green sturgeon in terms of repeated migration between two specific locations (M. Thomas, UCD, pers.comm.). From one of these locations spawning was confirmed through the results of this study, the other was not sampled. It is highly likely that the unusual occurrence of the 10 green sturgeon deaths in 2007 (NMFS 2008) was the result of green sturgeon spawners staging between upstream and downstream spawning habitats through the course of their normal spawning behavior as was noted for white sturgeon in the Kootenai River, Idaho (Paragamian and Kruse 2001). The emergency gate closure in 2007 may have temporarily blocked individuals from staging areas or spawning areas upstream of the dam. Individuals were then allowed free passage upstream during the mandatory 5 day gates raised period prior to the 4 month closure on May 15. Some green sturgeon may have unfortunately been caught by the dam as they traveled back downstream to staging areas or between spawning activities at potential secondary or tertiary spawning locations. In 2008, no emergency closure was implemented and tagged adults were not documented as having repeat migrations above and below RBDD prior to its closure (Israel et al. 2009).

To determine the effects of RBDD on green sturgeon, research efforts will need to be focused on determining the extent of the spawning habitat eliminated from access by upstream migrating adults under various RBDD operating scenarios, the possible effects of depensation through the allee effect (upstream of the dam) or the possibility of abnormally high egg predation levels or egg burying for those spawning at RBDD, and other related potential genetic implications of a dynamic barrier occurring within the spawning area of green sturgeon. More research under a variety of water year types to achieve full confidence concerning the timing and location of green sturgeon spawning events coupled with greater information on the microhabitats and water conditions in the Sacramento River will need to be known to configure habitat restoration actions or river flow manipulations to promote reproduction and survival of green sturgeon. Increased knowledge of spawning areas so biologists and managers can estimate the annual population of reproducing adults, monitor spawning activity and success, and assess habitat suitability is the foundation for appropriate management of the Sacramento River’s limited water resources. This knowledge would ultimately allow greater protection and recovery of the only currently known spawning population of SDPS green sturgeon.

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Tables

Table 1. Weekly rotational green sturgeon larval sampling matrix for the period May 26 – August 29, 2008. Sites were sampled Tuesdays and Thursdays in the mid-channel (M) or at bridge pilings on the river right (R) or river left (L) at RK 429 (Jelly's Ferry), RK 415 (Bend), RK 391 (RBDD), and RK 369 (Tehama). Sample times were between 21:39 and 00:53 (T_1) and 00:41 and 04:54 (T_2).

		T_1	T_2			T_1	T_2
5/26-5/30	RBDD	M	M	**6/2 - 6/6**	Tehama	R	L
	Tehama	L	-		RBDD	M	M
	Bend	L	R		Bend	R	L
	Jelly's	L	R		Jelly's	R	L
6/9 - 6/13	RBDD	M	M	**6/16 - 6/20**	RBDD	M	M
	Tehama	R	L		Tehama	L	R
	Jelly's	R	L		Jelly's	L	R
	Bend	R	L		Bend	L	R
6/23 - 6/27	Tehama	L	R	**6/30-7/4**	Tehama	R	L
	RBDD	M	M		RBDD	M	M
	Bend	L	R		Bend	R	L
	Jelly's	L	R		Jelly's	R	L
7/7 - 7/11	RBDD	M	M	**7/14 - 7/18**	RBDD	M	M
	Tehama	L	R		Tehama	R	L
	Jelly's	L	R		Jelly's	R	L
	Bend	L	R		Bend	R	L
7/21 - 7/25	Tehama	L	R	**7/28-8/1**	Tehama	R	L
	RBDD	M	M		RBDD	M	M
	Bend	L	R		Bend	R	L
	Jelly's	L	R		Jelly's	R	L
8/4 - 8/8	RBDD	M	M	**8/11 - 8/15**	RBDD	M	M
	Tehama	L	R		Tehama	R	L
	Jelly's	L	R		Jelly's	R	L
	Bend	L	R		Bend	R	L
8/18 - 8/22	Tehama	L	R	**8/25 - 8/29**	Tehama	R	L
	RBDD	M	M		RBDD	M	M
	Bend	L	R		Bend	R	L
	Jelly's	L	R		Jelly's	R	L

Table 2. Summary of green sturgeon egg sampling effort in wetted mat days (one sampler set for 24 hours) at three sites on the upper Sacramento River, CA.

Location	MicroHabitat[1]	Start Date	End Date	Single Mat Effort (d)	Paired Mat Effort (d)
Massacre Flats (RK 424.5)	Upstream	4/22/08	7/3/08	143.21	71.61
	Within	4/22/08	8/1/08	202.80	101.40
	Tail	4/22/08	7/15/08	159.73	79.86
RBDD (RK 391)	3D Mat	5/29/08	6/10/08	15.87	7.94
	Egg Roll	5/29/08	5/30/08	0.99	-----
	Egg Mat	5/28/08	7/18/08	171.92	85.96
Antelope Creek (RK 377)	Upstream	4/22/08	7/3/08	142.48	71.24
	Within	4/25/08	8/1/08	191.95	95.98
	Tail	4/22/08	7/18/08	172.61	86.31
			Total	1,201.58	600.29

[1] Microhabitats were not designated at quasi-natural site (RBDD below dam gate hydraulics); effort tallied by egg sampling design type.

Table 3. 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
5/2/08	424.5	6	4/30/08; 10:30	18	Small blastopore
5/2/08	424.5	1	4/30/08; 10:30	16-17	Mid-size yolk plug
5/2/08	424.5	2	4/30/08; 10:30	-	Fertilized & died, 2nd egg too crushed
5/6/08	424.5	1	5/3/08; 10:30	19-20	Early neurulation
5/9/08	377	1	5/9/08; 6:00	3	Grey crescent
5/9/08	377	1	5/8/08; 10:00	12	Late blastula, egg chorion broke open during exam
5/13/08	377	2	5/12/08; --	-	Fertilized & died, 2nd egg too crushed.
5/20/08	377	1	5/15/08; --	30	Heart tube formation and tail tip approaches the heart
5/20/08	377	4	5/17/08; 6:00	23	Closed neural tube
5/20/08	377	1	5/17/08; 6:00	17	Yolk plug
5/20/08	377	1	5/17/08; 6:00	23	Closed neural tube
5/20/08	377	1	5/17/08; 6:00	13	Death at gastrulation
6/6/08	377	6	6/5/08; 22:30	10-11	Late cleavage to early blastula
6/6/08	377	3	6/5/08; 22:30	10-11	-
6/6/08	377	1	6/5/08; 22:30	5-6	Stopped at 2nd or 3rd cleavage
6/6/08	377	1	6/5/08; 22:30	11	-
6/6/08	377	1	6/5/08; 22:30	11	-
6/6/08	377	1	6/5/08; 22:30	-	Semi-crushed GS egg; no obvious signs if fertilized initially
6/10/08	377	1	6/7/08; 10:30	25	Development of posterior trunk and tail regions
6/10/08	377	1	6/7/08; 10:30	-	GS egg-crushed; cannot say if it was viable and then died
6/10/08	377	1	6/9/08; 22:30	9-10	Late cleavage
6/10/08	377	1	6/9/08; 22:30	-	Semi-crushed GS egg; no obvious signs of initial fertilization

Table 3 Continued.

Date	River KM	Egg Count	Spawn Date/Time	Stage	Comments
6/13/08	424.5	1	6/10/08; 22:30	19	Early neurulation
6/20/08	391	1	6/19/08; 8:30	13	Early gastrulation
7/7/08	377	1	7/4/08; 22:30	20	Early neurulation
Total		42			

Table 4. Summary of approximate egg mat depths recorded during the 2008 green sturgeon egg mat sampling season.

		Sample Depths (m)		
Sample Location	**Microhabitat**	**Minimum**	**Average**	**Maximum**
Massacre Flats (RK 424.5)	Upstream	1.25	1.69	2.59
	Within	2.90	5.02	7.25
	Tail	1.07	1.74	5.18
RBDD (RK 391)	N/A	0.46	0.89	1.89
Antelope Creek (RK 377)	Upstream	2.04	2.40	3.11
	Within	3.47	4.75	7.56
	Tail	0.82	1.56	2.59

Table 5. Total stratified sampling effort for green sturgeon larvae for the period May 27 – August 15, 2008. Sampling occurred between the hours of 21:39 and 00:53 (T_1) and 00:41 and 04:54 (T_2). Sampling from bridge pilings occurred at Jelly's Ferry Bridge and Bend Bridge on river right (BP_1) and river left (BP_2). All sampling at RBDD was conducted from the Bypass Outfall in the middle of the river channel (Mid-channel). Tehama Bridge sampling occurred at the most river right bridge piling (BP_1) and the next adjacent piling towards river center (BP_2).

	Mid-channel		**BP_1**		**BP_2**		
Sample Site	T_1	T_2	T_1	T_2	T_1	T_2	**Effort (min)**
Jelly's Ferry Bridge (RK 429)	N/A	N/A	364	369	373	383	1,489
Bend Bridge (RK 415)	N/A	N/A	368	363	394	388	1,513
RBDD Bypass Outfall (RK 391)	901	682	N/A	N/A	N/A	N/A	1,583
Tehama Bridge (RK 369)	N/A	N/A	310	368	310	427	1,415
Total							6,000

Table 6. Exploratory sampling effort for green sturgeon larvae during the period May 27 – August 15, 2008. Exploratory sampling occurred at all four Tehama Bridge Pilings (1-4), both accessible Woodson Bridge pilings (1, 2) and the RBDD Bypass Outfall (Mid-channel). Bridge pilings were numbered from river right towards river left.

Sample Site	Mid-channel	1	2	3	4	Effort (min)
RBDD Bypass Outfall (RK 391)	318	N/A	N/A	N/A	N/A	318
Tehama Bridge (RK 369)	N/A	93	92	703	696	1,584
Woodson Bridge (RK 352)	N/A	54	181	N/A	N/A	235
Total						2,137

Table 7. Approximate river water depth of benthic D-net as taken from stern of sampling boat. Bridge pilings were numbered from river right towards river left. RBDD Bypass Outfall was located mid-channel. One sample was taken at Woodson Bridge piling 1; standard deviation not applicable.

		River Depth (m)			
SampleSite	**Bridge Piling**	**Minimum**	**Average**	**Maximum**	**St Dev**
Jelly's Ferry Bridge (RK 429)	1	6.40	9.24	16.50	3.96
	2	10.10	11.85	12.90	0.78
Bend Bridge (RK 415)	1	2.70	3.75	4.60	0.67
	2	8.90	9.92	10.70	0.56
RBDD Bypass Outfall (RK 391)	--	2.50	6.26	7.50	1.09
Tehama Bridge (RK 369)	1	6.00	6.37	7.10	0.40
	2	6.00	6.76	7.20	0.45
	3	5.80	9.05	10.50	1.35
	4	3.50	5.58	7.00	1.44
Woodson Bridge (RK 352)	1	23.40	23.40	23.40	--
	2	13.80	14.30	15.80	1.00

Table 8. Summary of information derived from larval green sturgeon samples captured at the RBDD Bypass Outfall (RK 391) Sacramento River, CA. Estimated spawn date was back calculated based on larval stage (Dettlaff et al. 1993), developmental rates of green sturgeon (Deng et al. 2002; Van Eenennaam et al. 2005), and mean daily Sacramento River water temperatures.

Capture Date	Estimated Spawn Date	Developmental Stage	Total Length (mm)	Estimated Days to Hatch	Estimated Age Post Hatch (days)
6/17/08	5/28 - 5/30/08	45 (complete yolk sac absorption)	25	7	12-14
6/17/08	5/28 - 5/30/08	45 (complete yolk sac absorption)	24	7	12-14
6/17/08	5/28 - 5/30/08	45 (complete yolk sac absorption)	26	7	12-14
7/15/08	6/25 - 6/27/08	45 (complete yolk sac absorption)	25	7	12-14

Figures

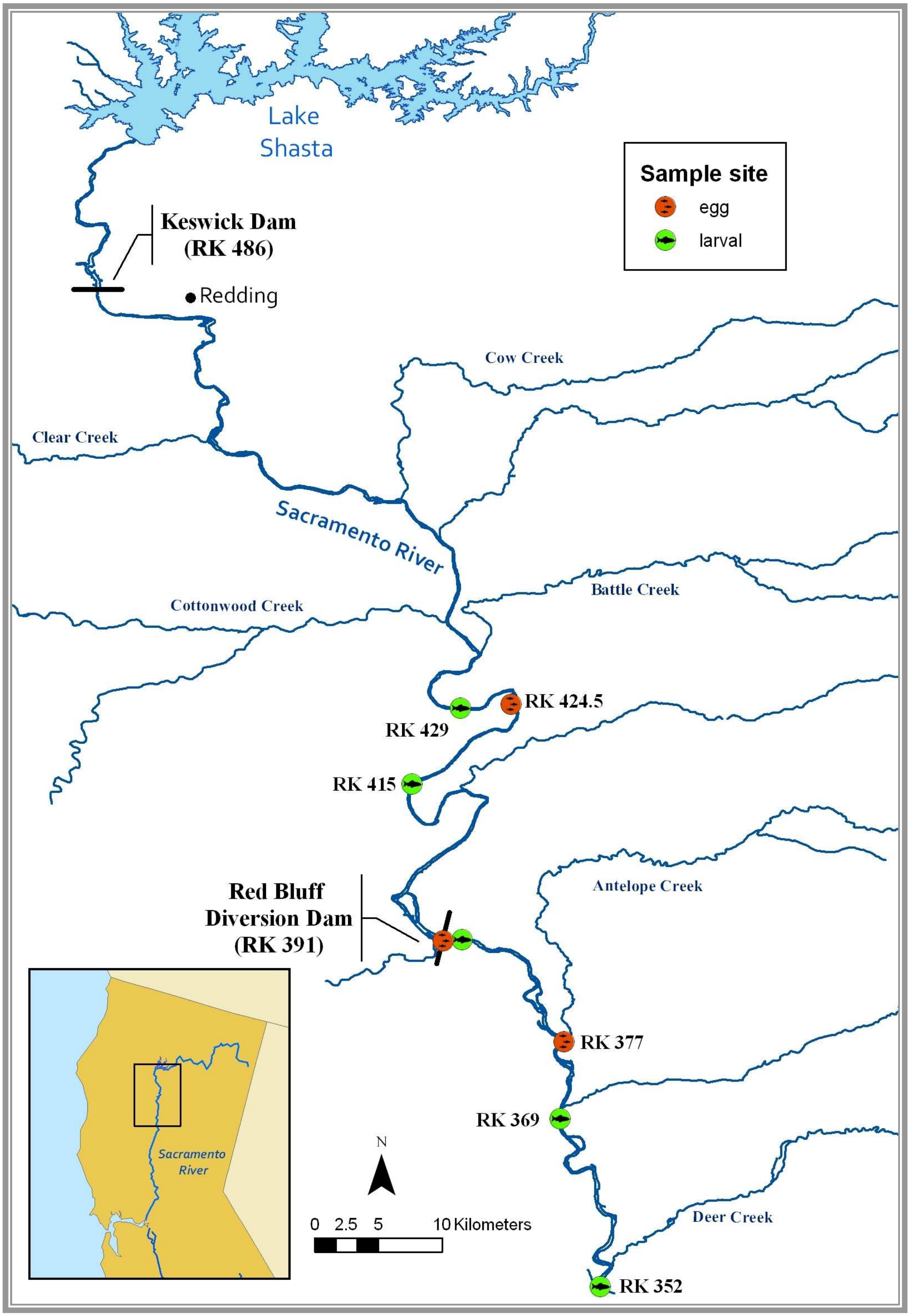

Figure 1. Locations of green sturgeon egg and larvae sample sites in the upper Sacramento River, CA.

Figure 2. Artificial substrate samplers used to sample for green sturgeon eggs in the upper Sacramento River; a) egg mat; b) egg tube; c) egg roll.

Figure 3. Underwater video camera with sounding weights and 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.

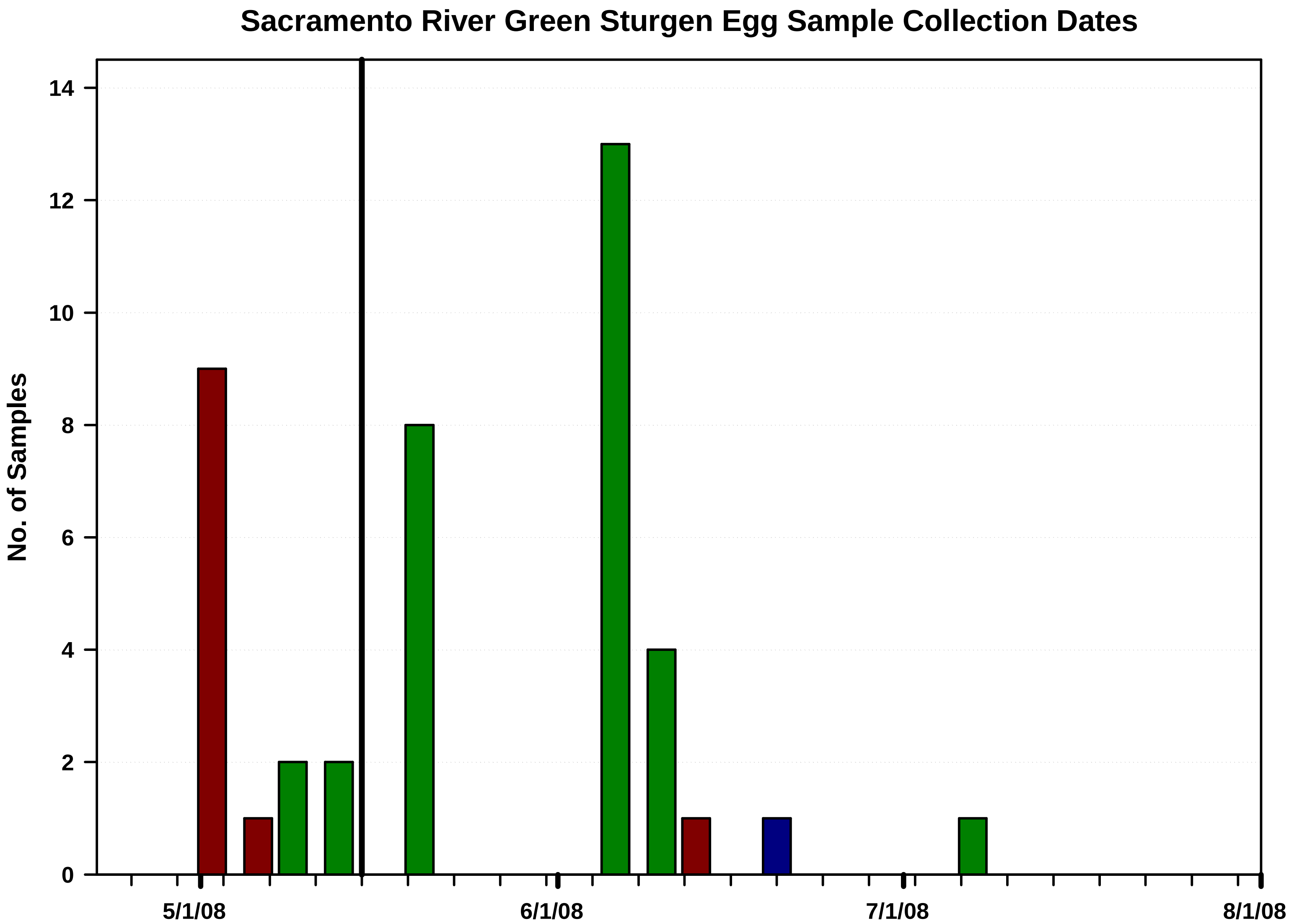

Figure 5. Temporal distribution of green sturgeon egg samples collected at RK 424.5 (red bars), RK 391 (blue bars), and RK 377 (green bars) on the Sacramento River, CA. Black vertical line indicates lowering of the RBDD gates on May 15, 2008.

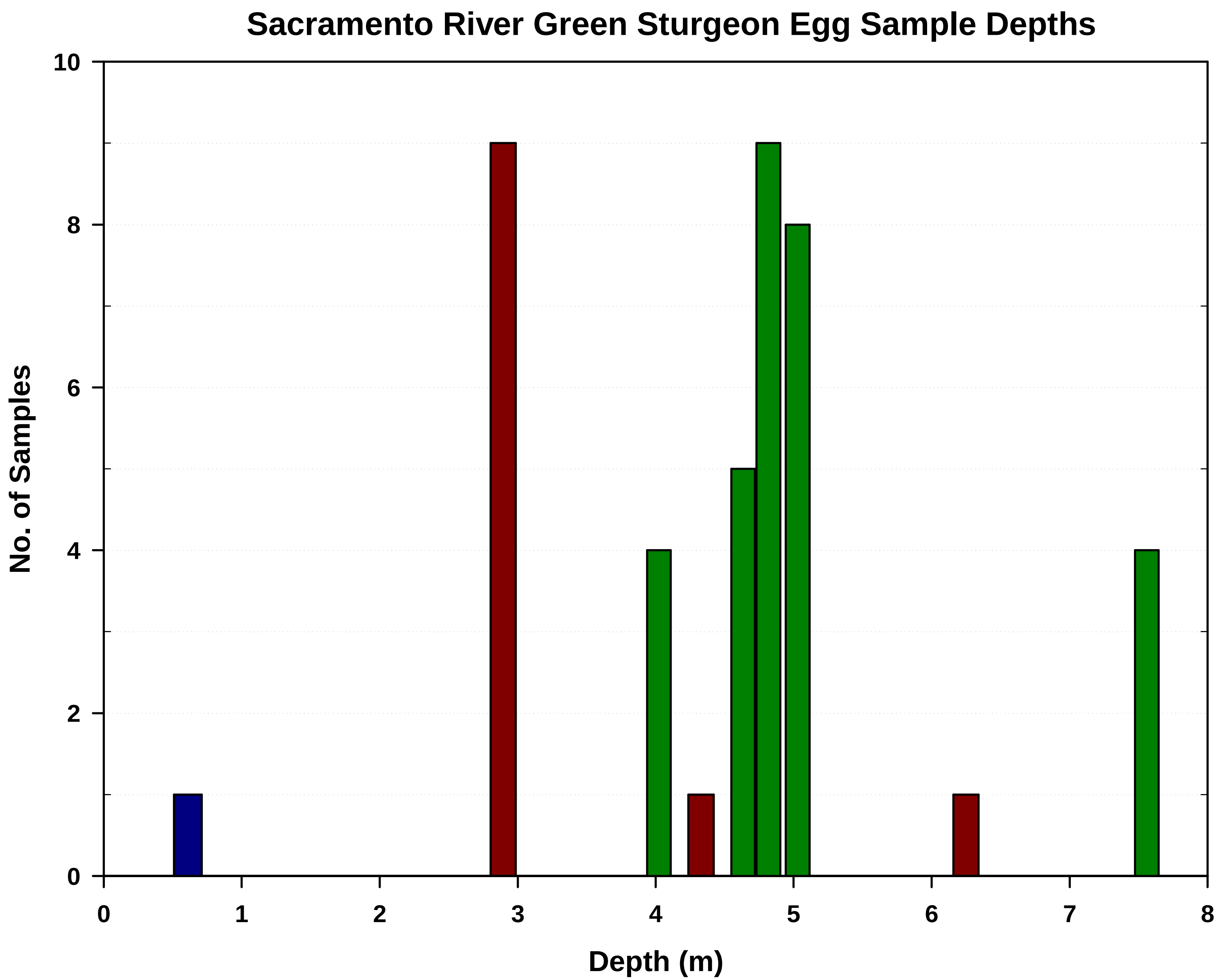

Figure 6. River depth of green sturgeon eggs sampled from egg mats at RK 424.5 (red bars), RK 391(blue bars), and RK 377 (green bars) on the Sacramento River, CA for the period May 2 - July 7, 2008.

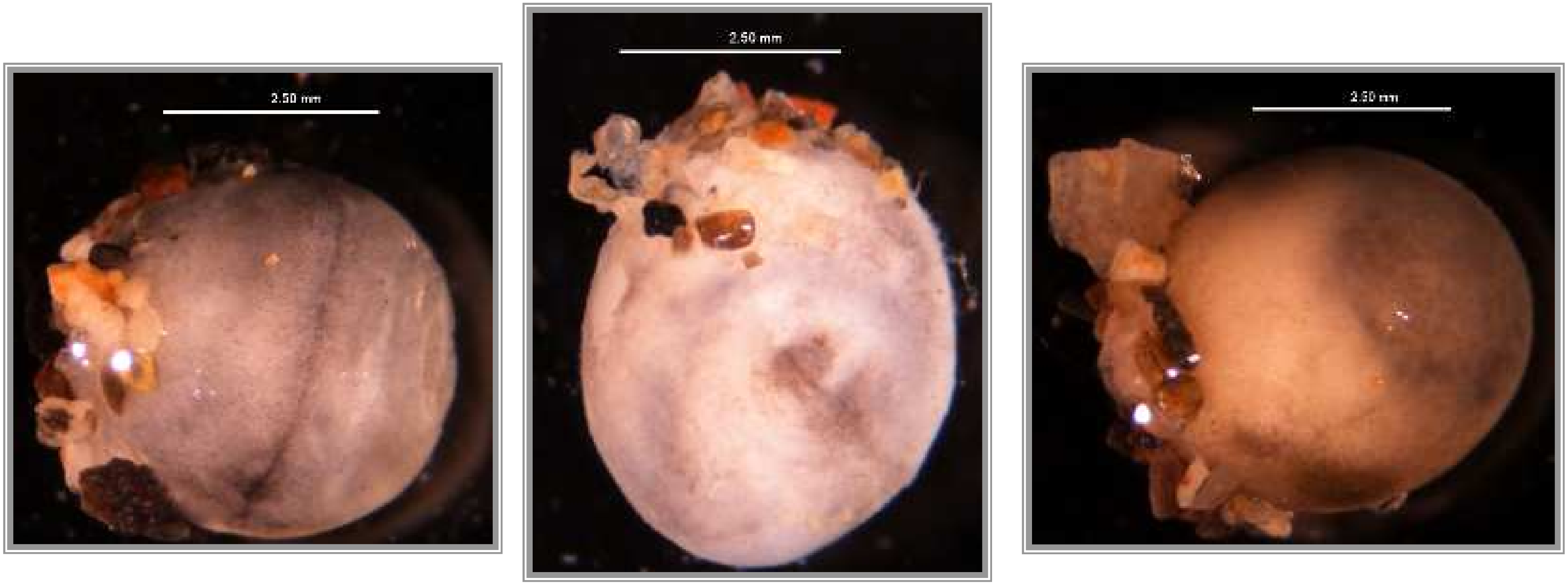

Figure 7. Photos of three green sturgeon eggs (various stages of development) sampled during egg mat sampling. Note sand adhered to each egg, indicating an adhesive jelly coat.

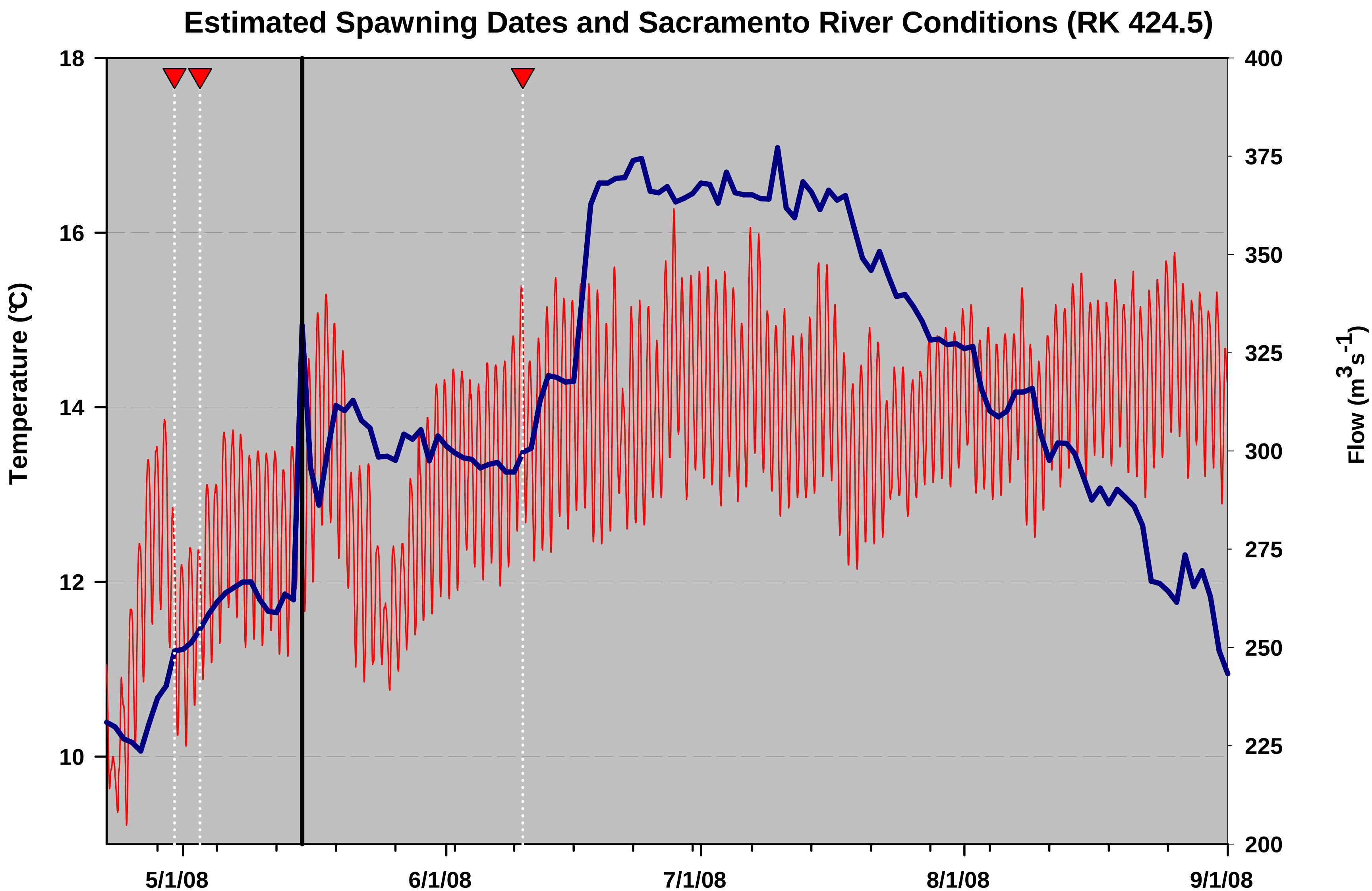

Figure 8. Estimated green sturgeon spawning dates (inverted red triangles), Sacramento River mean daily flow (dark blue), and hourly temperature (red) at Massacre Flats (RK 424.5). Black vertical line indicates when RBDD gates were lowered on May 15, 2008.

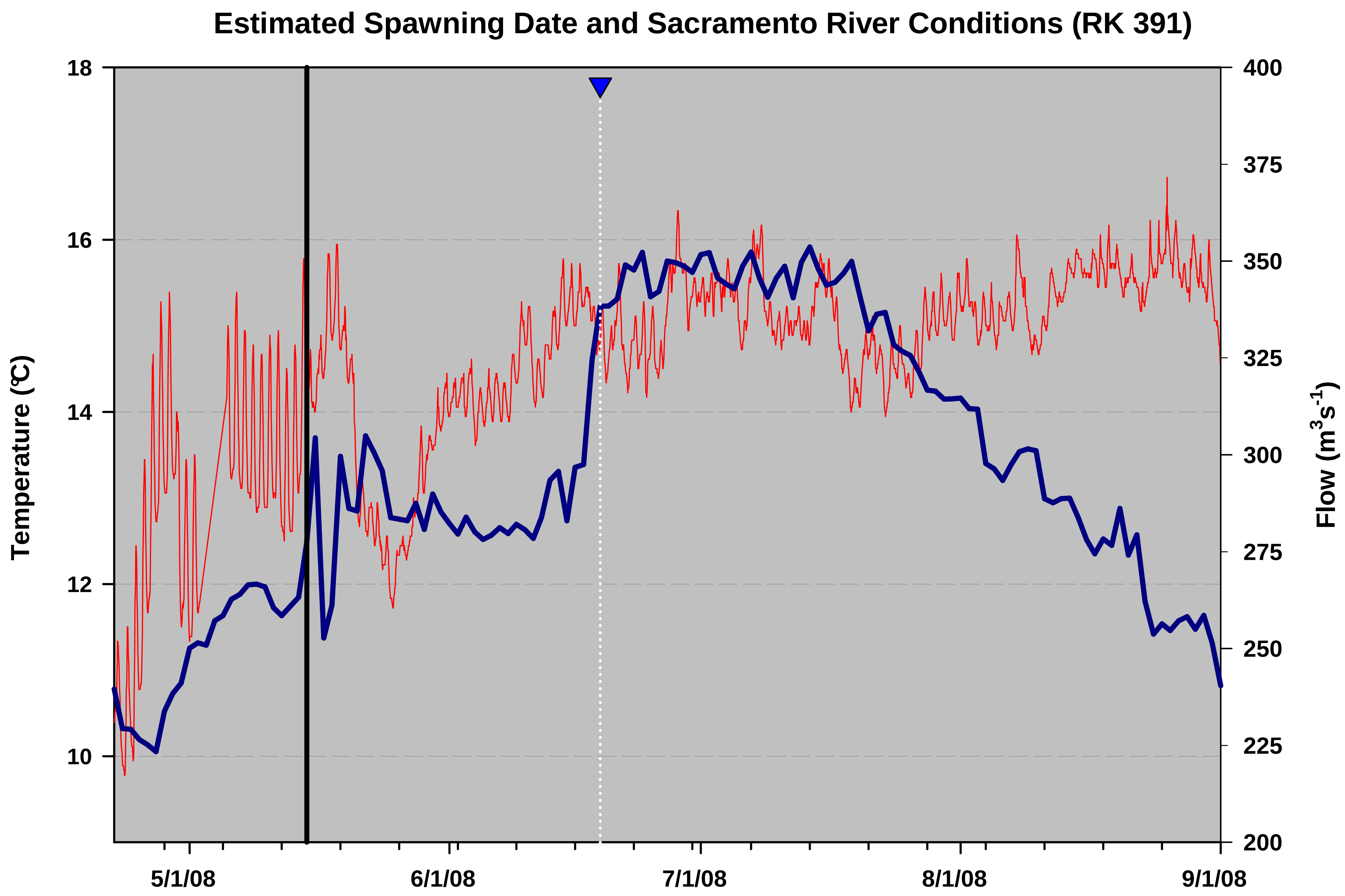

Figure 9. Estimated green sturgeon spawning date (inverted blue triangle), Sacramento River mean daily flow (dark blue), and hourly temperature (red) at Red Bluff Diversion Dam (RK 391). Black vertical line indicates when RBDD gates were lowered on May 15, 2008.

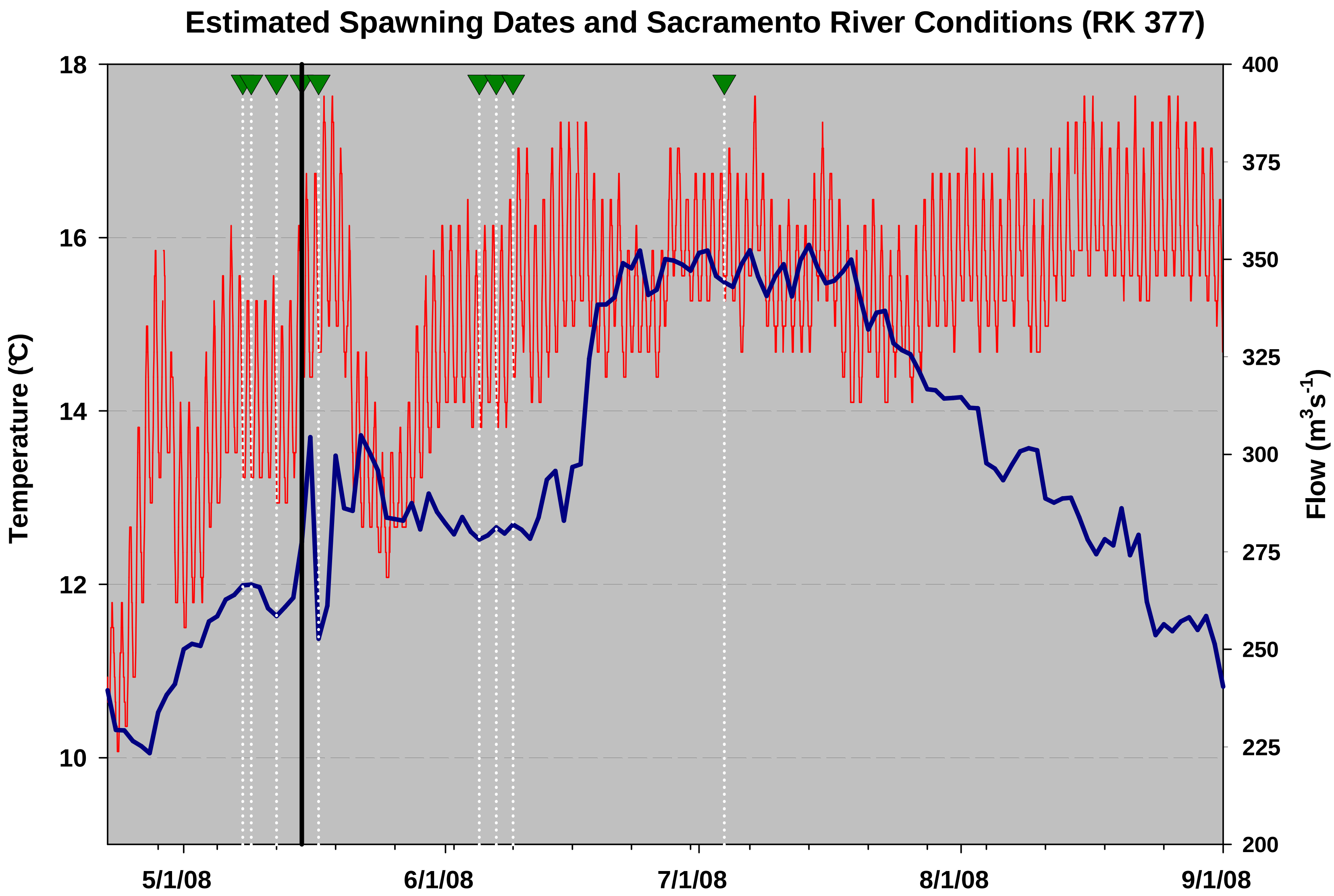

Figure 10. Estimated green sturgeon spawning dates (inverted green triangles), Sacramento River mean daily flow (dark blue), and hourly temperature (red) at mouth of Antelope Creek (RK 377). Black vertical line indicates when RBDD gates were lowered on May 15, 2008.

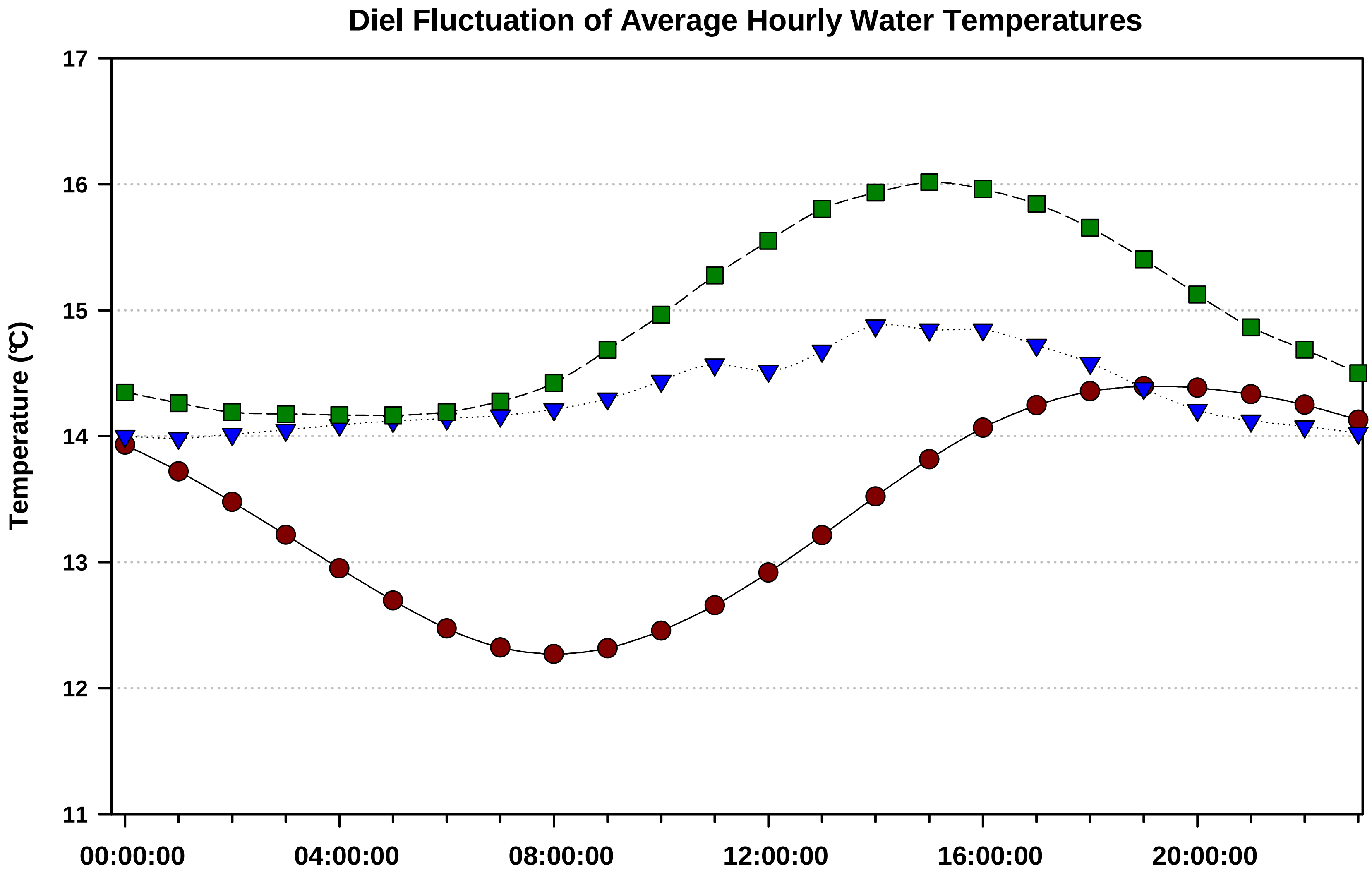

Figure 11. Average hourly Sacramento River water temperatures at RK 424.5 (red circle), RK 391 (blue triangle), and RK 377 (green square) for the period April 22 to August 15, 2008. Time at midnight noted as 00:00:00.

Appendix

APPENDIX I (List of Tables)

Table **Page**

Table A1. Summarized species capture results by location from the 2008 green sturgeon larval sampling efforts; bridges denoted as Br.

Species	Jelly's Ferry Br.	Bend Br.	RBDD Bypass Outfall	Tehama Br.	Woodson Br.	Total
American shad (egg)	0	1	2	807	5	815
Chinook salmon	1	1	5	0	0	7
Cottid fry	1	1	16	12	0	30
Cyprinid fry	14	32	152	327	8	533
Green sturgeon	0	0	4	0	0	4
Lamprey fry	2	5	0	9	2	18
Leech	0	1	0	0	0	1
Prickly sculpin	0	0	7	1	1	9
Rainbow trout	3	2	0	0	0	5
Riffle sculpin	0	0	2	3	0	5
Sacramento sucker	7	4	23	32	0	66
Three spine stickleback	0	0	4	0	0	4
Unknown	1	0	2	0	0	3
Unknown (egg)	2	0	0	1	0	3
Unknown invertebrate	0	1	0	0	0	1