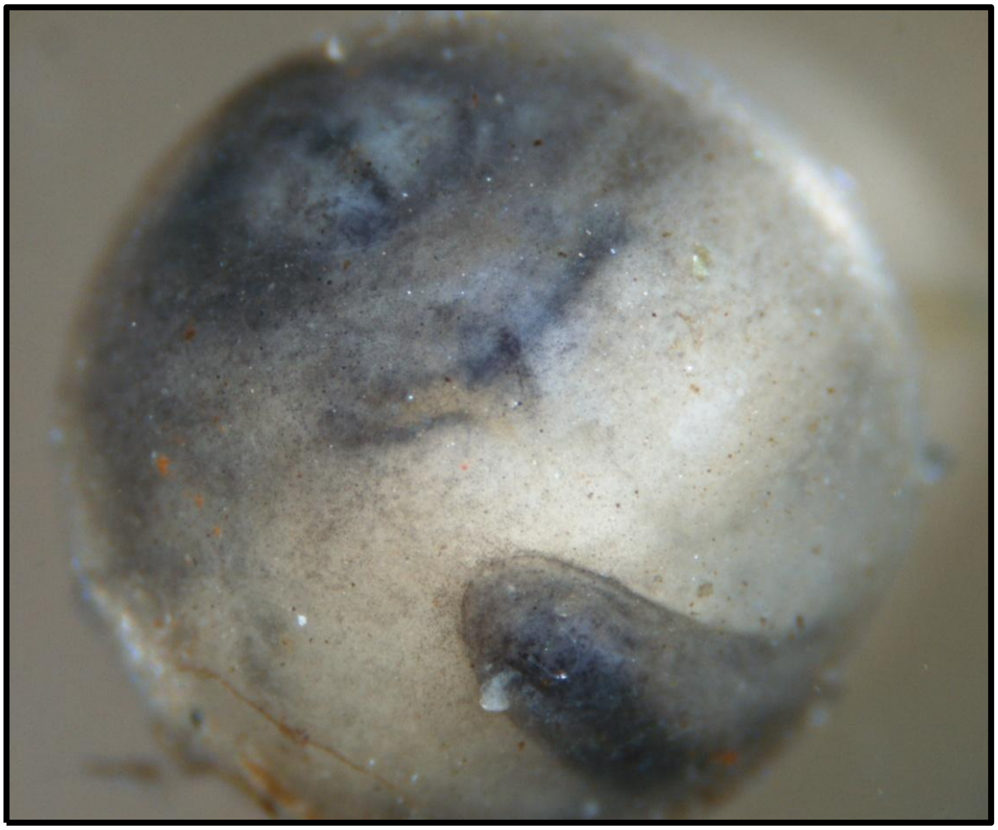
2012 San Joaquin River Sturgeon Spawning Survey

Final Annual Report



Prepared by:

Zachary J. Jackson[1]* and Joel P. Van Eenennaam[2]

[1]U.S. Fish and Wildlife Service
Stockton Fish and Wildlife Office
850 Guild Avenue, Suite 105
Lodi, California 95240

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

*Corresponding author: Zachary_Jackson@fws.gov

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Cover Photo: White sturgeon egg sampled from the San Joaquin River on 2 April 2012 using artificial substrate samplers. Photo courtesy of University California-Davis using an Olympus dissecting microscope and a Nikon DS-U1 digital camera.

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Preface

The following is the final report for the U.S. Fish and Wildlife Service's investigations on anadromous sturgeon spawning in the San Joaquin River between RK 119 and RK 143, funded by the Central Valley Project Improvement Act (CVPIA) Anadromous Fish Restoration Program in Fiscal Year 2012. Title 34, Section 3406(b)(1) of the CVPIA, Public Law 102-575, requires the Secretary of the Interior to develop within three years of enactment and implement a program which makes all reasonable efforts to ensure that, by the year 2002, natural production of anadromous fish in Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967-1991. Section 3406(b)(1) also states that "this goal shall not apply to the San Joaquin River between Friant Dam and the Mendota Pool."

The purpose of these investigations is to provide scientific information to the Central Valley Project Improvement Act Anadromous Fish Restoration Program to assist in developing restoration recommendations that will help meet program objectives and achieve its anadromous fish doubling goal.

2012 San Joaquin River Sturgeon Spawning Survey

Zachary J. Jackson

U.S. Fish and Wildlife Service, Stockton Fish and Wildlife Office,
850 Guild Avenue, Suite 105, Lodi, California 95240, USA

Joel P. Van Eenennaam

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

Abstract.— Several researchers have suggested that sturgeon (genus Acipenser) may spawn occasionally in the San Joaquin River during high-water years. Initial documentation of white sturgeon *Acipenser transmontanus* spawning in the San Joaquin River system occurred in 2011 near Grayson, CA (river kilometer 142, rkm, measuring from its confluence with the Sacramento River). However, whether sturgeon spawn in the San Joaquin River in normal and drier water year types remained unknown. Artificial substrate samplers (i.e., egg mats) were deployed at four sites within a 24-km reach of the San Joaquin River from Sturgeon Bend (rkm 119) to Grayson Road Bridge (rkm 143) from 16 February to 1 June 2012. During the sample period, 65 white sturgeon eggs were collected among four sites, 45 of which were viable and between developmental stages 4 and 28. Based upon capture location, date of capture, water temperature, stage of development, and the assumption that a female takes 12–20 hours to release all of her eggs, the eggs likely represent at least six different females that spawned between 20 March and 14 May 2012. The results of this survey confirm that white sturgeon do spawn in the San Joaquin River in both wet- and dry-year conditions and may be an important source of production for the white sturgeon population in the Sacramento-San Joaquin river system.

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Introduction

Two species of sturgeon (genus Acipenser), white sturgeon *A. transmontanus* and green sturgeon *A. medirostris,* occur in California. Migration and spawning of both white sturgeon and green sturgeon in the Sacramento River system has been well documented by direct observation, angler catch, and detection of eggs, larvae, and young-of-the-year sturgeon (Kohlhorst 1976; Schaffter 1997; Beamesderfer et al. 2004; Poytress et al. 2009, 2010, 2011). Several researchers have speculated that sturgeon also spawn within the San Joaquin River system occasionally (Kohlhorst 1976; Schaffter 1997; Beamesderfer et al. 2004), such as 'when flows and water quality permit' (Moyle 2002). However, spawning had not been confirmed through any direct sampling activities in the San Joaquin River, California until recently when fertilized white sturgeon eggs were collected by the U.S. Fish and Wildlife Service (USFWS; Gruber et al. 2012).

Information regarding sturgeon distribution in the San Joaquin River was limited to anecdotal reports and California Department of Fish and Wildlife (CDFW) sturgeon report card data (Gleason et al. 2008; DuBois et al. 2009, 2010, 2011, 2012). Information regarding sturgeon habitat use and movements throughout the San Joaquin River is lacking, but critical to improve management and protection of these species. Angler fishing report cards (Gleason et al. 2008; DuBois et al. 2009, 2010, 2011, 2012) document a small sturgeon fishery in the reach of the San Joaquin River upstream of Stockton, California (river kilometer, hereafter rkm, 64; Figure 1). Since implementation of the Sturgeon Report Card in 2007, anglers have reported catching 169 white sturgeon and 6 green sturgeon on the San Joaquin River upstream from Stockton (Gleason et al. 2008; DuBois et al. 2009, 2010, 2011, 2012). Of the reported fish, 108 (64%) white and 5 (83%) green sturgeon were caught between Stockton and the Highway 140 bridge (rkm 202). The remaining 61 (36%) white and 1 (17%) green sturgeon were caught upstream of the Highway 140 bridge. Reports indicated anglers concentrate in two areas known locally as Sturgeon Bend (rkm 119) and Laird Park (rkm 143; H. Rutherford, CDFW warden, personal communication). Additionally, anglers and game wardens indicate that sturgeon caught during March and April commonly expel milt or eggs during handling, indicating that spawning could be occurring nearby.

The primary focus of this study was to determine if sturgeon are spawning in the San Joaquin River in various water-year types by collecting fertilized sturgeon eggs on artificial substrate samplers. Understanding the spatial and temporal distribution of sturgeon in the San Joaquin River is vital for the management and recovery of these important species. Further, understanding the physical characteristics of the areas being used by sturgeon will help identify future restoration actions.

Study Area

The San Joaquin River originates from the central Sierra Nevada and drains parts of the Sierra Nevada and Diablo ranges. It flows through 531 km of the state, first west towards the floor of the Central Valley of California, then north towards the Sacramento-San Joaquin Delta, eventually reaching the Pacific Ocean. Friant Dam (rkm 431), constructed in 1942, forms a complete barrier to upstream anadromous fish passage. Downstream of Friant Dam, the river encounters increasingly greater anthropogenic influence through water diversions and habitat alteration. Sampling occurred at four locations in a 24-km reach of the San Joaquin River from Sturgeon Bend (rkm 119) to Grayson Road Bridge (rkm 143) in Stanislaus County, CA (Figure 1).

Methods

Sturgeon eggs were sampled by deploying artificial substrate samplers (i.e., egg mats) in close proximity to presumed spawning areas based on hydraulic conditions, side-scan sonar images, and angler and warden observations. Egg mats were constructed from two 89 x 65-cm rectangular sections of furnace filter material secured back to back within a welded steel framework (McCabe and Beckman 1990; Schaffter 1997; 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 2.0-kg anchor attached to the upstream end of the egg mat with two 76-cm lengths of 9.5-mm diameter braided polypropylene rope. A labeled float was attached to the downstream end of each egg mat with a 9.5-mm diameter braided polypropylene rope. Float line length varied between egg mats, depending on water depth and velocity. Mats were predominantly deployed in areas of accelerating velocities (i.e., areas flanking deepest portions of pools) and were set in pairs. Sampling occurred from 16 February to 1 June 2012.

Environmental and sample effort data were collected during both the setting and retrieval of egg mats. Environmental data consisted of depth, GPS coordinates, temperature, turbidity, river discharge, and weather condition. Depth (m) and GPS coordinates were recorded directly above each egg mat with a Lowrance depth finder (Model StructureScan HDS 10-m). Hourly water temperature was monitored at each egg mat with a temperature logger (Model Stowaway Tidbit). Turbidity (nephelometric turbidity units, NTUs) was measured with a Hach turbidimeter (Model 2100P). All discharge data were obtained through the California Data Exchange Center. Discharge data for rkm 119 were obtained from the gauging station located near Vernalis, CA. Discharge data for rkm 131 were estimated by subtracting Stanislaus River discharge at Ripon, CA from the discharge reported at Vernalis. Discharge data for rkm 142 and 143 were obtained from the gauging station located near Patterson, CA. Sample effort data consisted of the date and time individual egg mats were set and retrieved.

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

All eggs removed from the egg mats were counted and identified to species in the field with an egg key (Reyes et al. 2007; Wang 2010; Reyes 2011). All suspected sturgeon eggs and unidentified eggs were placed into vials of 95% ethyl alcohol (EtOH) for laboratory identification and further analysis. Suspected sturgeon eggs were sent to the University of California-Davis (UCD) for species confirmation, photography, measurement of egg diameter, and determination of developmental stage (Dettlaff et al. 1993). Egg length and width were measured (± 0.001 mm) with 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.

Estimates of date and time of fertilization (i.e., spawn timing) were based on an average water temperature for the time period between egg collections, estimated egg developmental stage, and rates of embryonic development established for white sturgeon (Wang et al. 1985, 1987).

Results

Cumulative egg mat sampling totaled 670.9 wetted mat days (wmd; one mat set for 24 hours) between four sample sites (Table 1). Eighty-two percent (552.3 of 670.9 wmd) of the total sampling effort was expended approximately evenly across three sample sites downstream of Laird Park (rkm 119, rkm 131, and rkm 142). Mats were added at the rkm 143 site during the sixth week of sampling due to observations of sturgeon in the area, which accounted for 17.7% of total effort (118.5 wmd).

Sixty-five white sturgeon eggs were collected among four sampling sites between 20 March and 14 May 2012 and transferred to UCD for analysis. Twenty eggs (31%) were not viable, many of which were covered in fungus. It could not be determined if these were fertilized eggs that died during embryogenesis or were un-fertilized eggs (Table 2). Forty-five eggs (69%) were viable and determined to be in various stages of post-fertilized embryonic development (Table 2; Dettlaff et al. 1993).

Egg mats were deployed at river depths ranging from 0.4–9.3 m (μ = 3.8 m; Table 3). Egg samples were collected from mats deployed at depths ranging from 1.6–9.1 m with a mean depth of 3.8 m. San Joaquin River water temperatures recorded during the study are summarized in Table 4. Daily average water temperatures ranged from 12.8–19.4 °C (μ = 16.3 °C) at the lowest site (rkm 119; Figure 2), 13.1–24.9 °C (μ = 18.7 °C) at rkm 131 (Figure 3), 13.4–24.8 °C (μ = 19.2 °C) at rkm 142 (Figure 4), and 16.1–24.7 °C (μ = 20.8 °C) at rkm 143 (Figure 5) during the sample period. The 19 April egg collections at rkm 142, and the 10 May collections at the rkm 142 and 143 sites, included the highest recorded hourly water temperatures during the period from estimated spawn timing until collection, ranging from 18.2–20.9 °C, 19.7–23.2 °C , and 19.7–23.0 °C, respectively (Table 4). San Joaquin River discharge ranged from 35.0–125.1 $m^3 s^{-1}$ (μ = 63.0 $m^3 s^{-1}$) at rkm 119 (Figure 2), 20.0–80.5 $m^3 s^{-1}$ (μ = 35.2 $m^3 s^{-1}$) at rkm 131 (Figure 3), and 12.7–43.0 $m^3 s^{-1}$ (μ = 21.6 $m^3 s^{-1}$) at the upper sites (rkm 142 and 143; Figures 4 and 5) throughout the sample period (Table 5). Turbidity grab samples ranged from 9.3–68.3 nephelometric turbidity units (NTU) among sites during the sample period and from 19.0–63.9 NTU among sites on days when eggs were collected.

Minimum and maximum egg diameter were measured in the lab on 88% (n = 57) of egg samples after carefully removing attached debris. Lab measurements were not taken on eggs that had become covered in fungus (n = 8), making accurate measurements of size impossible. The mean maximum diameter (as the eggs are slightly oblong in shape) was 3.54 mm ± 0.10 (ranging 3.35–3.76 mm), and mean minimum diameter was 3.40 mm ± 0.11 (ranging 3.11–3.62 mm).

Discussion

During 2012, egg mat sampling identified white sturgeon spawning at four locations extending over 24 km of the San Joaquin River. Eggs were collected at rkm 119, 131, 142, and 143 on one, one, four, and two occasions, respectively (Table 2), representing at least six distinct spawning events. On two occasions, eggs were collected at successive sampling sites on the same day. Whether or not the eggs collected on 2 April and 10 May 2012 at both the rkm 142 and 143 sites at similar stages of embryogenesis were from the same female or different females cannot be concluded. Given the time over which a female spawns (12–20 hours; J. P. Van Eenennaam, unpublished) and the proximity of the sites, it is possible that a single female spawned at both sites. However, future genetic analyses may be able to confirm whether the sampled eggs were from a single female or from multiple females.

Optimal spawning temperatures for white sturgeon have been reported to be 10–18°C in the Columbia River (Parsley et al. 1993; McCabe and Tracy 1994). Kohlhorst (1976) reported the optimal spring spawning temperature for white sturgeon to be 14–16°C in the Sacramento River. Optimal temperatures for development and survival of white sturgeon embryos are reported to be 14–17°C, with hatching rates decreasing at 20°C and complete arrest of embryonic development at 23°C in laboratory experiments (Wang et al. 1985). Although some of the days during the one-week spawning and embryo incubation period had elevated water temperatures above what has been reported as optimal, there were no obvious signs of deformities at the stages of embryonic development observed in any viable eggs that were collected. However, it is at later stages of embryogenesis and post-hatch larvae when obvious problems have been observed that were related to elevated incubation temperature in green sturgeon embryos (e.g., substantial shortening of the embryo body, decrease in percent dry weight, lordosis, kyphosis, edema; Van Eenennaam et. al. 2005). Fertilization and early cleavage stages did not appear to be affected by temperature in the majority of the eggs, as abnormal cleavage could lead to gastrulation arrest and, consequently, mortality before neurulation (Sytina and Shagaeva 1987). Sytina and Shagaeva (1987) also reported the complete block of egg cleavage at temperatures outside the spawning range (e.g., ≥ 28°C) in stellate sturgeon *A. stellatus*.

One may question whether the percent of non-viable eggs (31%) could be related to the elevated temperatures; however, some of these non-viable eggs were found early in the spawning season when temperatures were closer to optimal. A number of factors other than temperature may be causing or contributing to mortality of embryos, including sampling related damage and contaminants.

Several of the viable eggs were almost completely covered in sand particles which were carefully removed by gently scraping the egg with fine needle forceps until the stage of development could be discerned (Figure 6). Kock et al. (2006) suggest that sediment cover may be an important early life stage mortality factor in rivers where white sturgeon spawn over fine substrates. Eggs completely buried in shifting sand would likely die from lack of oxygen. Efforts to accurately characterize the substrate types present in the known spawning areas have been initiated, but are not complete. Regardless, the river bed within the sampling area is dominated by sand and silt substrates. However, if the eggs are attached to cobble or other types of large substrate and become coated in silt or sand as the jelly coat forms, they will likely remain viable as long as they are exposed to sufficient water flow. The degree of jelly coat formation on fertilized sturgeon eggs is not fully understood, but recent work has documented variations among species (Van Eenennaam et al. 2012).

California Department of Fish and Wildlife Sturgeon Report Card data indicate six green sturgeon and 169 white sturgeon were reported by anglers in the last five years within the San Joaquin River upstream of Stockton, five of which were caught in March and April (Gleason et al. 2008; DuBois et al. 2009, 2010, 2011, 2012). Although the data indicate the presence of a limited number of green sturgeon, it is possible that some fish go unreported (e.g., poaching; Beamesderfer et al. 2004) or are misidentified as white sturgeon. It remains unknown how and to what extent green sturgeon use the San Joaquin River. However, the reported presence of green sturgeon in the San Joaquin River coincides with the spawning migration period of the Southern Distinct Population Segment of green sturgeon within the Sacramento River (Poytress et al. 2009, 2010, 2011). Although there is a temporal overlap in spawn timing between white and green sturgeon (Kohlhorst 1976; Poytress et al. 2009), no documentation exists where these two sturgeon species spawn in close proximity to each other. Turbidity may be driving the separation of spawning locations. Generally, green sturgeon spawn in areas where turbidity is less than 10 NTU (Poytress et al. 2009, 2010, 2011). Conversely, white sturgeon spawn in areas that are generally turbid in nature (μ = 42 NTU; Perrin et al. 2003). Because of elevated turbidity levels in the San Joaquin River, we hypothesize that green sturgeon on a spawning run within the San Joaquin River system may be seeking less turbid water upstream of the sampled area in the mainstem or within one of the tributaries where turbidity is lower. Therefore, focusing future egg sampling efforts between rkm 119 and rkm 143 may limit the ability to detect spawning green sturgeon in the San Joaquin River.

In addition to egg sampling, larval sampling with a benthic D-net has been accepted as an effective method to document the spawn timing of sturgeon species (Kohlhorst 1976). Although larval samples will not provide information on specific spawning locations, methods from Dettlaff et al. (1993) can be used to estimate spawn timing. Larval captures could help determine if there were deformities at hatch, but many deformed larvae would likely be unable to “swim-up” and thus captures would be expected to be rare. Larval captures would confirm the presence or absence of normal swim-up larvae during the periods of elevated water temperatures. The bridge abutments at the Airport Way (rkm 116) and

Grayson Road (rkm 143) crossings provide an ideal tie-off location for larval D-net sampling of known white sturgeon spawning locations at rkm 119, 131, 142, and 143. Larval sampling at these two locations would provide the opportunity for detection of larval green sturgeon dispersing from speculated spawning locations within the Stanislaus, Tuolumne, Merced, or upper San Joaquin rivers. Furthermore, without documentation of larval white sturgeon in the San Joaquin River upstream of the Delta, it is unknown if spawning events within the San Joaquin River are a source of larval production for the Sacramento-San Joaquin white sturgeon population.

Average daily discharge in the San Joaquin River in early 2011 was two to three times higher than the mean daily discharge for water years 1993 to 2012 (Figure 7). As speculated by researchers (e.g., Kohlhorst 1976; Schaffter 1997; Moyle 2002; Beamesderfer et al. 2004), river discharge levels of this magnitude may have triggered white sturgeon to enter and spawn within the San Joaquin River in 2011. River discharge levels in 2012 were generally half or less than the 20-year average. However, documentation of at least six distinct spawning events during 2012 show that spawning also occurs in dry years and may occur annually. There was a general trend of collecting eggs around short-duration peaks in river discharge during the 2012 sampling season (Figures 2, 3, 4, and 5). Spring pulses of discharge from the Merced and Tuolumne rivers in late April and early May intended to increase survival of emigrating salmonids preceded collection of white sturgeon eggs at all four sampling locations. Water temperatures at most sampling sites had been over 18°C and increasing for several weeks, yet a late peak in spawning activity occurred around the time that short-duration increases in discharge from the tributaries arrived at the sampling locations. This suggests the possibility that there were a number of white sturgeon holding in the lower San Joaquin River that responded to the change in environmental conditions (e.g., river discharge, temperature) to initiate spawning.

Additional sturgeon egg and larval sampling, in conjunction with acoustic tracking of adults, should be continued throughout a variety of water year types to better understand the spatial and temporal distribution and habitat preferences of white sturgeon in the San Joaquin River. Continued study of the response of white sturgeon to changes in river discharge and temperature may be important for informing fishery and water management decisions. Understanding the effects of water management in a regulated system like the San Joaquin River may result in increased spawning activity, spawning success, and recruitment of white sturgeon. Additionally, a better understanding of white sturgeon distribution and use and the potential to encounter various life-history stages of green sturgeon within this system may enhance the understanding and ability to manage for both species.

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Tables

Table 1.—Location of sites sampled on the San Joaquin River, California, by river kilometer (rkm), dates sampled, effort in wetted mat days, and the proportion of effort at each site in relation to total effort expended during 2012 egg sampling. A wetted mat day is equivalent to one mat set for 24 hours.

Sample site (rkm)	Sample dates	Wetted mat days	% Effort
119	16 Feb – 1 Jun	188.6	28.1%
131	16 Feb – 1 Jun	181.7	27.1%
142	16 Feb – 1 Jun	182.0	27.1%
143	22 Mar – 1 Jun	118.5	17.7%
Total Effort	16 Feb – 1 Jun	670.9	100.0%

Table 2.—Size, collection location, estimated spawn timing, and developmental stage of white sturgeon eggs collected on the San Joaquin River, California during 2012.

Sample date	Location (rkm)	Egg diameter (mm)		Spawning		Developmental stage	Comments
		Min	Max	Date	Hours		
22 Mar	142	3.368	3.468	-	-	-	not viable
22 Mar	142	3.433	3.512	-	-	-	not viable
22 Mar	142	3.302	3.370	21 Mar	0035	18	blastopore closure
22 Mar	142	3.522	3.543	-	-	-	marbled, not viable
22 Mar	142	3.349	3.402	-	-	-	marbled, not viable
22 Mar	142	3.435	3.641	20 Mar	1835	19	early neurulation
22 Mar	142	3.359	3.414	-	-	-	marbled, not viable
22 Mar	142	-	-	-	-	-	crushed, appears not viable
22 Mar	142	3.490	3.490	-	-	-	marbled, not viable
22 Mar	142	3.263	3.720	-	-	-	oblong shaped, early neurulation
22 Mar	142	3.416	3.567	-	-	-	marbled, not viable
22 Mar	142	3.177	3.422	20 Mar	1835	19	early neurulation
22 Mar	142	3.226	3.615	20 Mar	1835	19	early neurulation
22 Mar	142	3.198	3.584	20 Mar	1835	19	early neurulation
22 Mar	142	3.303	3.598	20 Mar	1835	19	early neurulation
22 Mar	142	3.461	3.573	20 Mar	1835	19	early neurulation
22 Mar	142	3.602	3.691	20 Mar	1835	19	early neurulation
22 Mar	142	3.356	3.731	-	-	-	oblong, not viable
22 Mar	142	-	-	-	-	-	collapsed/crushed
22 Mar	142	3.259	3.426	-	-	-	
22 Mar	142	3.302	3.611	20 Mar	1835	19	early neurulation
22 Mar	142	3.573	3.602	20 Mar	1835	19	early neurulation
22 Mar	142	3.365	3.546	20 Mar	1835	19	early neurulation
22 Mar	142	3.415	3.581	20 Mar	1835	19	early neurulation
22 Mar	142	3.491	3.759	-	-	-	marbled, not viable
22 Mar	142	3.370	3.552	20 Mar	1835	19	early neurulation
2 Apr	[a]	3.575	3.591	31 Mar	am	22	initial separation of tail region
2 Apr	[a]	-	-	-	-	-	fungus covered, not viable
2 Apr	[a]	3.335	3.346	31 Mar	am	22	initial separation of tail region

Table 2. —Continued (See page 14 for heading).

Sample date	Location (rkm)	Egg diameter (mm) Min	Egg diameter (mm) Max	Spawning Date	Spawning Hours	Spawning	Comments
2 Apr	[a]	-	-	-	-	-	fungus covered, not viable
2 Apr	[a]	3.345	3.385	31 Mar	am	22	initial separation of tail region
2 Apr	[a]	3.390	3.599	31 Mar	am	22	initial separation of tail region
2 Apr	[a]	3.397	3.516	-	-	-	some fungus, not viable
2 Apr	[a]	3.614	3.614	31 Mar	am	22	initial separation of tail region
19 Apr	142	-	-	-	-	-	collapsed/crushed sturgeon egg
19 Apr	142	3.472	3.478	18 Apr	0313	22	late-neurulation
19 Apr	142	3.113	3.449	18 Apr	0313	22	late-neurulation
19 Apr	142	3.437	3.476	18 Apr	0313	22	late-neurulation
19 Apr	142	3.345	3.453	-	-	-	marbled, not viable
10 May	142	3.432	3.708	8 May	1911	26	initial separation of tail region
10 May	142	3.472	3.531	8 May	1911	26	initial separation of tail region
10 May	142	3.366	3.691	8 May	1911	26	initial separation of tail region
10 May	143	-	-	-	-	-	fungus covered, not viable
10 May	143	3.443	3.575	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.302	3.435	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	-	-	-	-	-	fungus covered, not viable
10 May	143	3.539	3.598	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.354	3.368	-	-	-	marbled, not viable
10 May	143	3.509	3.617	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.388	3.495	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.615	3.673	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.567	3.612	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.330	3.526	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	3.579	3.616	8 May	1317	28	separated tail and straight cardiac tube
10 May	143	-	-	-	-	-	fungus covered, not viable
14 May	131	3.365	3.545	13 May	0612	18	blastopore closure
14 May	131	3.416	3.586	13 May	0612	18	blastopore closure
14 May	131	3.536	3.711	13 May	0612	18	blastopore closure

Table 2. —Continued (See page 14 for heading).

Sample date	Location (rkm)	Egg diameter (mm)		Spawning		Spawning	Comments
		Min	Max	Date	Hours		
14 May	131	3.402	3.456	13 May	0612	18	blastopore closure
14 May	131	3.363	3.590	13 May	0612	18	blastopore closure
14 May	119	3.292	3.500	13 May	1540	14	Gastrulation
14 May	119	3.289	3.369	14 May	0040	14	Gastrulation
14 May	119	3.303	3.472	14 May	0040	14	Gastrulation
14 May	119	3.402	3.476	14 May	0040	14	Gastrulation
14 May	119	3.473	3.474	14 May	0740	4	2-cell

*****Spawning date and time was estimated by back-calculation based on the developmental stage of embryogenesis (Dettlaff et al. 1993), developmental rates of white sturgeon (Deng et al. 2002), and daily water temperatures recorded on temperature loggers attached to the egg mats on the San Joaquin River.

[a]Eggs were collected at both the rkm 142 and 143 sites on 2 April, 2012. However, due to lost datasheets, it is impossible to tell which eggs and how many were collected at each site.

Table 3.— Minimum, maximum, and mean depths of sites sampled with egg mats during 2012 in the San Joaquin River, California. Sample sites expressed as river kilometers (rkm), depths (m) sampled at each site throughout the season, and depths (m) of mats that collected white sturgeon eggs.

	Sample depths (m)			White sturgeon egg sample depths (m)		
Sample site (rkm)	Min	Max	Mean	Min	Max	Mean
119	1.0	9.3	5.4	5.8	9.1	7.1
131	0.5	9.1	4.6	4.2	5.2	4.7
142	1.1	4.1	2.8	1.6	3.8	2.7
143	0.4	2.1	1.4	1.6	1.6	1.6
All sites	0.4	9.3	3.8	1.6	9.1	3.8

Table 4.— Minimum, maximum, and mean hourly water temperatures for each sample site for the duration of the study and during the period from estimated spawn timing to collection for each white sturgeon egg collection in the San Joaquin River, California during 2012.

Sample site (rkm)	Sample date	Sample hourly temperatures (ºC)			Spawn timing to collection hourly temperatures (ºC)		
		Min	Max	Mean	Min	Max	Mean
119	14 May	11.7	20.4	16.2	17.2	18.6	17.8
131	14 May	12.0	26.6	18.7	17.0	19.0	18.1
142	22 Mar	12.1	26.8	19.3	14.2	16.6	15.7
142	19 Apr	12.1	26.8	19.3	18.2	20.9	19.5
142	10 May	12.1	26.8	19.3	19.7	23.2	21.3
143[a]	10 May	14.7	26.3	20.8	19.7	23.0	21.3
[b]	2 Apr	12.1	26.8	19.3	15.8	18.6	17.4
All sites		12.0	26.8	18.8	14.2	16.6	18.1

[a]Sample hourly temperatures for rkm 143 were based on data from 9 April-29 May 2012.

[b]Eggs were collected at both the rkm 142 and 143 sites on 2 April, 2012. However, due to lost datasheets, it is impossible to tell which eggs and how many were collected at each site. Spawn timing to collection hourly temperatures were calculated with temperature data gathered at rkm 142 due to an incomplete sample range at rkm 143.

Table 5.—Minimum, maximum, and mean daily river discharge for each sample site for the duration of the study and during the period from estimated spawn timing to collection for each white sturgeon egg collection in the San Joaquin River, California during 2012.

		Sample discharge (m^3s^{-1})			Spawn timing to collection discharge (m^3s^{-1})		
Sample site (rkm)	Sample date	Min	Max	Mean	Min	Max	Mean
119	14 May	35.0	125.1	63.0	124.1	125.1	124.6
131	14 May	20.0	80.5	35.2	80.5	80.5	80.5
142	22 Mar	12.7	43.0	21.6	34.2	35.8	34.9
142	19 Apr	12.7	43.0	21.6	25.5	31.4	28.5
142	10 May	12.7	43.0	21.6	30.3	34.7	32.9
143	10 May	12.7	43.0	21.6	30.3	34.7	32.9
[a]	2 Apr	12.7	43.0	21.6	19.6	20.5	20.2
All sites		12.7	125.1	35.3	19.6	125.1	50.6

[a]Eggs were collected at both the rkm 142 and 143 sites on 2 April, 2012. However, due to lost datasheets, it is impossible to tell which eggs and how many were collected at each site.

Figures

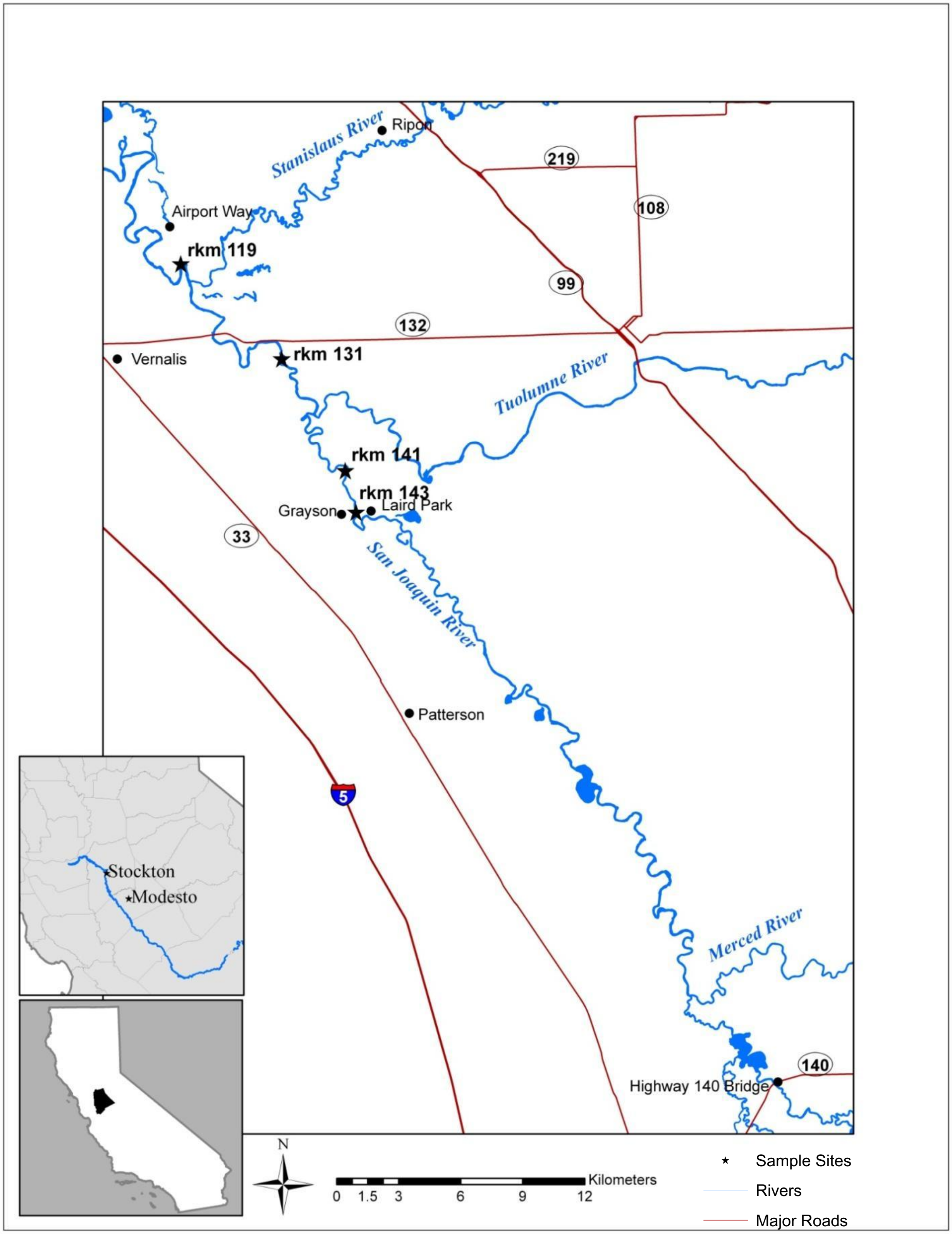

Figure 1.—Location of egg mat sample sites on the San Joaquin River, California between Sturgeon Bend (rkm 119) and Grayson Road Bridge (rkm 143).

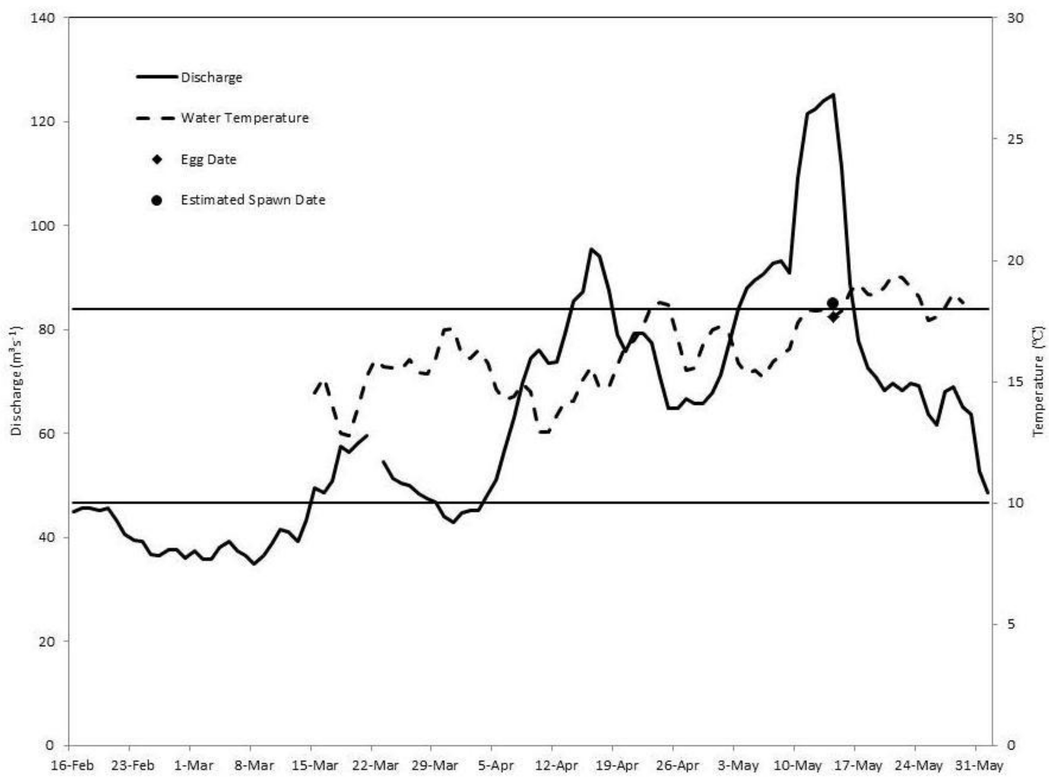

Figure 2.—Mean daily discharge (m^3 s^{-1}) and water temperature (°C) observed in 2012 on the San Joaquin River near rkm 119. The black parallelogram and the black circle represent the date when white sturgeon eggs were collected and the estimated spawn date, respectively, at rkm 119. Discharge and temperature measurements were obtained from the California Data Exchange Center for the gauging station near Vernalis, California and thermographs attached to individual egg mats, respectively. Horizontal bars indicate upper and lower optimal spawning temperatures for white sturgeon (Parsley et al. 1993; McCabe and Tracy 1994).

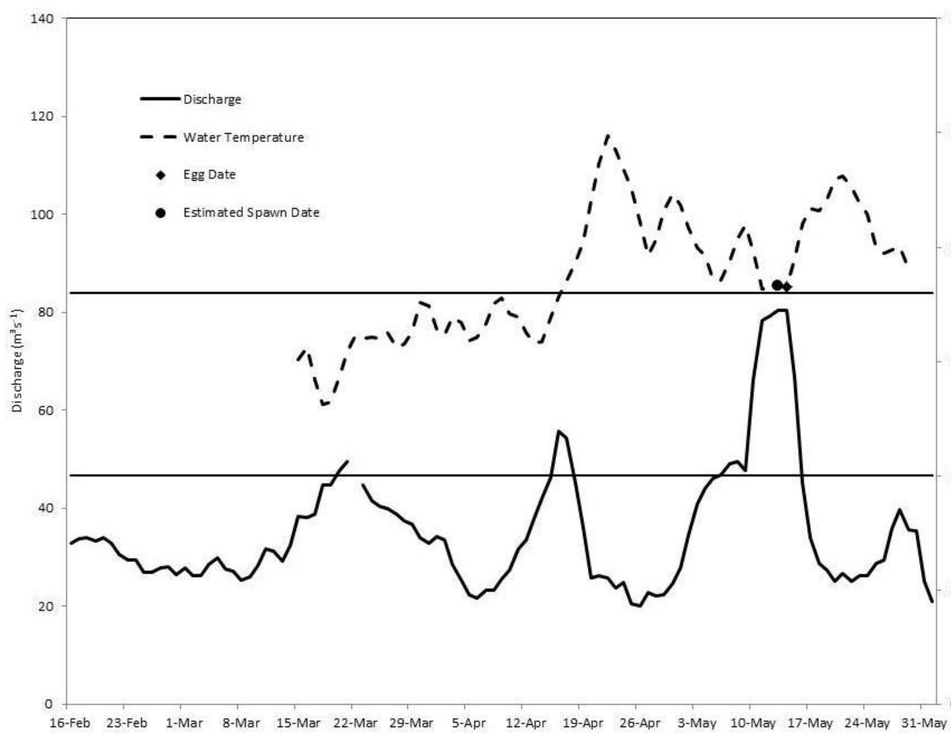

Figure 3.— Mean daily discharge (m^3 s^{-1}) and water temperature (°C) observed in 2012 on the San Joaquin River near rkm 131. The black parallelogram and the black circle represent the date when white sturgeon eggs were collected and the estimated spawn date, respectively, at rkm 131. Discharge data for rkm 131 were estimated by subtracting Stanislaus River discharge at Ripon from the discharge reported at Vernalis. Discharge and temperature measurements were obtained from the California Data Exchange Center and thermographs attached to individual egg mats, respectively. Horizontal bars indicate upper and lower optimal spawning temperatures for white sturgeon (Parsley et al. 1993; McCabe and Tracy 1994).

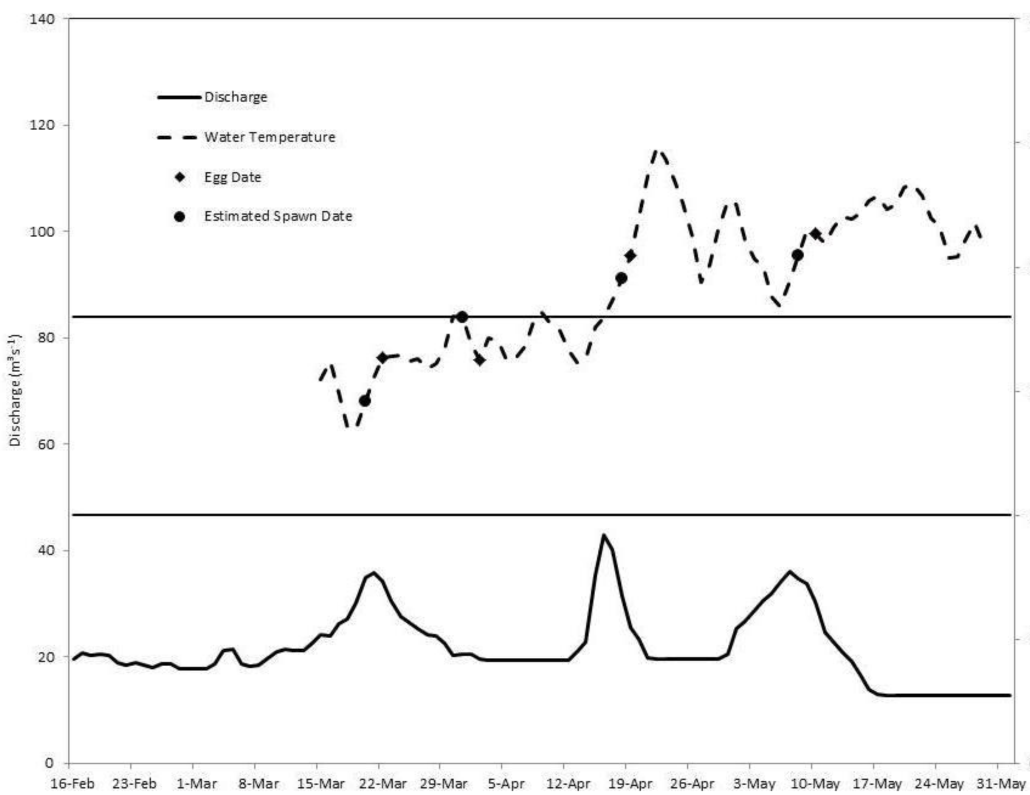

Figure 4.—Mean daily discharge ($m^3\ s^{-1}$) and water temperature (°C) observed in 2012 on the San Joaquin River near rkm 142. Black parallelograms and black circles represent dates when white sturgeon eggs were collected and the estimated spawn dates, respectively, at rkm 142. Discharge and temperature measurements were obtained from the California Data Exchange Center for the gauging station near Patterson, California and thermographs attached to individual egg mats, respectively. Horizontal bars indicate upper and lower optimal spawning temperatures for white sturgeon (Parsley et al. 1993; McCabe and Tracy 1994).

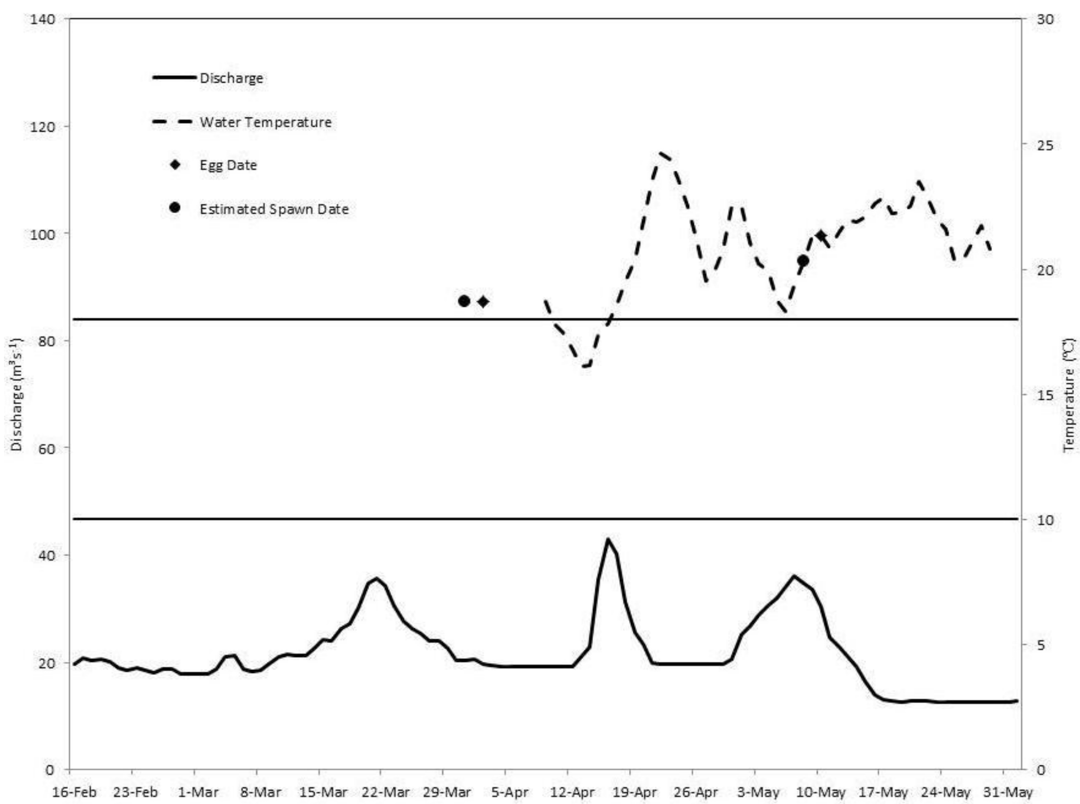

Figure 5.—Mean daily discharge (m^3 s^{-1}) and water temperature (°C) observed in 2012 on the San Joaquin River near rkm 143. Black parallelograms and black circles represent dates when white sturgeon eggs were collected and the estimated spawn dates, respectively, at rkm 143. Discharge and temperature measurements were obtained from the California Data Exchange Center for the gauging station near Patterson, California and thermographs attached to individual egg mats, respectively. Horizontal bars indicate upper and lower optimal spawning temperatures for white sturgeon (Parsley et al. 1993; McCabe and Tracy 1994).

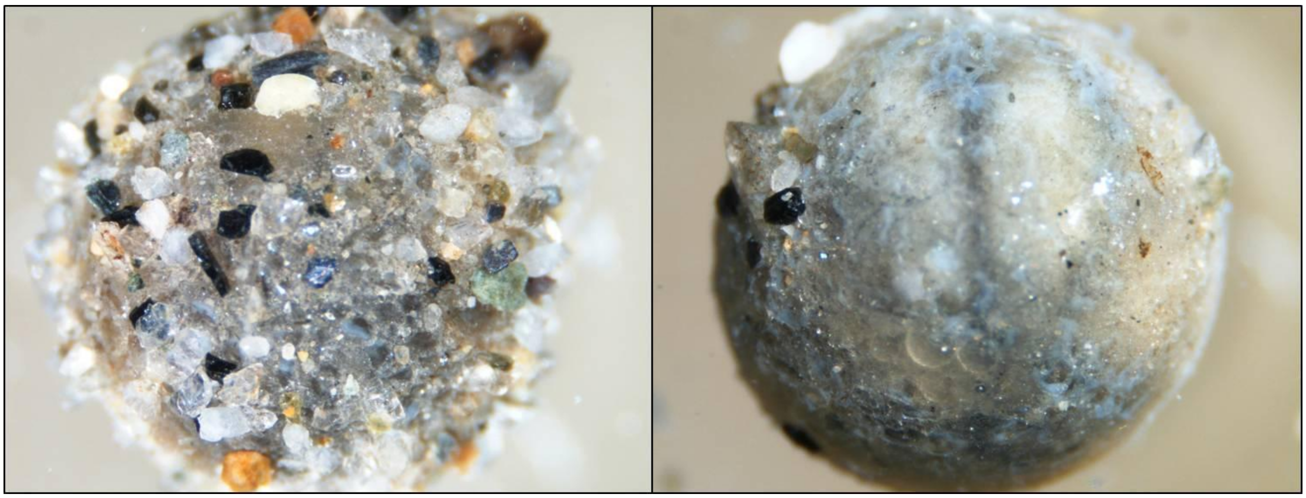

Figure 6.—White sturgeon egg collection from San Joaquin River in left panel. Right panel shows same egg after careful removal of fine sediment.

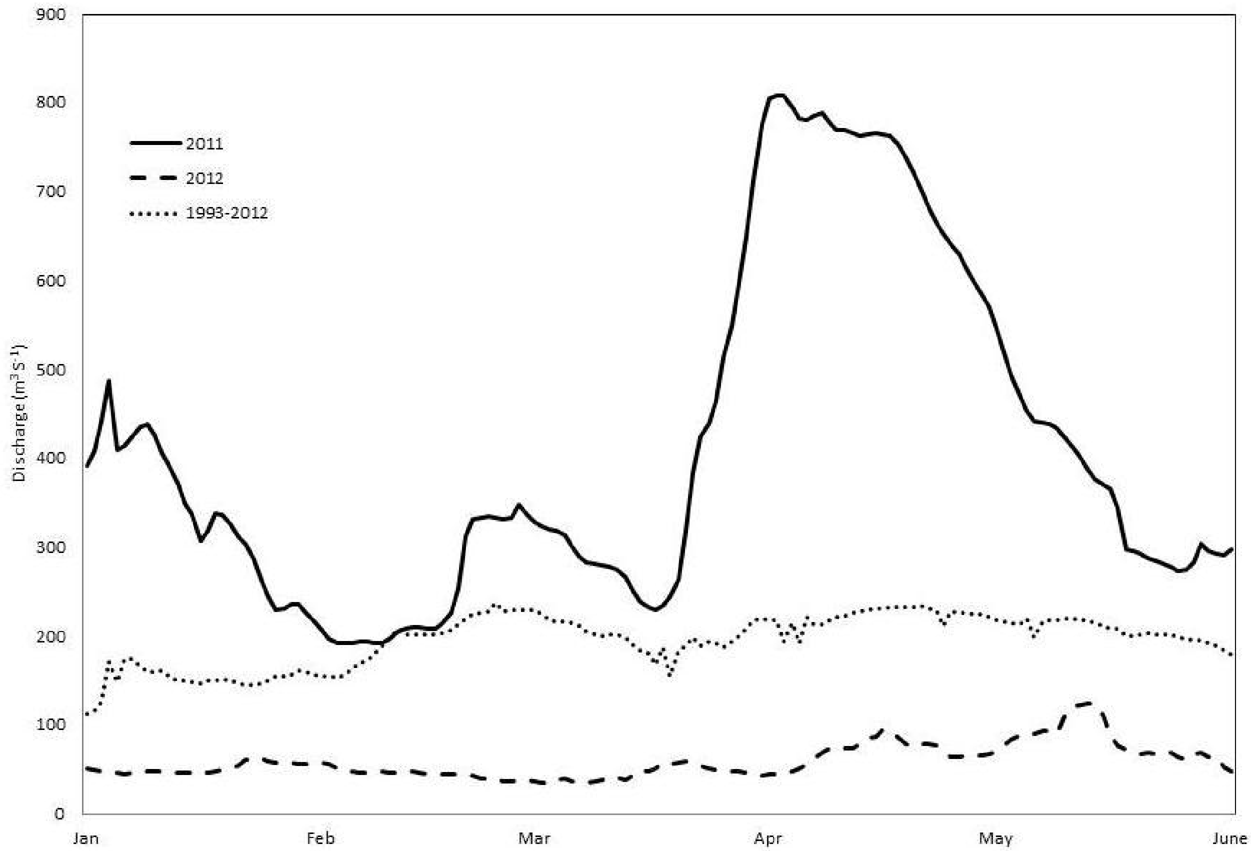

Figure 7.— San Joaquin River mean daily discharge ($m^3\ s^{-1}$) during the January through June period of 1993-2012 at the gauging station near Vernalis, California.