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M e m o r a n d u m

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Subject: 2023 Sacramento River Sturgeon Spawning Study

Purpose

The purpose of this report is to document findings regarding the 2023 sturgeon spawning survey to determine white sturgeon (*Acipenser transmontanus*) spawning locations in the Sacramento River and the associated temporal, spatial, and habitat parameters.

Background

White sturgeon (*Acipenser transmontanus*) populations have been severely reduced due to dams blocking access to much of their historical spawning grounds, diversions which entrain larval and juvenile sturgeon, habitat degradation, a legacy commercial fishery; legal sport harvest and illegal harvest (poaching). White sturgeon is a California state fish species of concern, and is an important recreational fishery managed by CDFW. Recent white sturgeon population monitoring, and population modeling data show a continued downward decline in the number of adult spawners in California (Blackburn et. al., 2018). The Sacramento River system is the primary river system supporting spawning of white sturgeon. The majority of white sturgeon are thought to

spawn in the middle Sacramento River between Knights Landing at river kilometer (rkm) 142 and Colusa at rkm 237 between mid-February and mid-May (Schaffter, 1997). Southern Distinct Population (sDPS) green sturgeon (*Acipenser medirostris*) are not known to spawn in the Sacramento River downstream of the Glenn-Colusa Irrigation District Diversion at rkm 332.5 (Poytress et. al, 2015). 2023 is the six consecutive year that a sturgeon spawning survey was conducted on the middle Sacramento River.

White sturgeon are aggregate broadcast spawners and typically spawn in deep pools or runs over sand, gravel, cobble, or bedrock substrates with swift or complex currents. Eggs are round or nearly so, dark gray in color, with diameters ranging from 3.2 mm to 4.0 mm (Van Eenennaam et al, 2006). Upon contact with water, the egg's surface becomes adhesive, and they readily stick to bottom substrates. The use of artificial substrates, such as egg mats, has been shown to be an effective method for documenting sturgeon spawning habitat through the collection of eggs. CDFW conducted a pilot sturgeon spawning survey in the Sacramento River between Knights Landing (river kilometer [rkm 144]) and Boyds Landing (rkm 171) in 2017 but no sturgeon eggs were observed. The 2018 spawning survey included four Sacramento River reaches: Colusa, Tisdale, Knights Landing, and Verona. No sturgeon eggs were collected during the study, although white sturgeon were observed breaching within the study reaches during several site visits (CDFW 2018). The 2019 spawning survey included two sites in the Knights Landing reach and three sites in the Colusa reach. No sturgeon eggs were collected during the 2019 spawning survey. The 2020 spawning survey included four sites in the Knights Landing reach. The Colusa or Tisdale reaches were not sampled in 2020 due to logistical issues resulting from Covid-19 work restrictions. No sturgeon eggs were collected during the 2020 survey. A single white sturgeon egg was collected from the Colusa reach during the 2021 white sturgeon spawning survey (CDFW 2022). A total of 42 white sturgeon eggs were collected during the 2022 survey (CDFW 2022).

Methods

CDFW North Central Region staff reviewed the report of findings of Schaffter (1997) and Kohlhurst (1976), and bathymetry data to determine potential spawning sites in two reaches of the Sacramento River. Site selection for egg mat deployment was based on flow habitat type (e.g., pool, deep run), water depth, and to a lesser extent, substrate composition. Suitable sturgeon spawning habitat typically consists of pools or deep runs with depths ranging from 1.8 to 11.2 meters and flow velocities of ≥ 1.0 meter per second with substrates consisting of gravel, cobble, and boulder (Poytress 2013, Schaffter 1997). Prior to the initial deployment of egg mats, CDFW staff conducted reconnaissance surveys using a Humminbird® multi-function depth-finder to locate sturgeon aggregations and determine substrate composition at potential sampling sites.

Egg mats were constructed by securing a furnace filter insert to a 76 × 107 × 5-cm rectangular steel frame; the mats were rigged with a 9.5-mm diameter braided polypropylene rope attachment bridle, 9.5-mm diameter buoy line of sufficient length, and a 25-cm diameter inflatable buoy to mark the egg mat location and facilitate retrieval. Once a sampling site was selected, the mat was deployed by gradually lowering it to the river bottom from the stern of the boat while holding the boat stationary in the current. When the egg mat reached the river bottom, the buoy and remaining buoy line were deployed and observed for several minutes to ensure the egg mat remained in place. Deployment date and time, GPS coordinates or waypoints; and water depth and temperature were recorded at each sampling site. GPS coordinates, river depth and water temperature were recorded with a Humminbird® multi-function depth-finder. Surface flow velocity estimated to the nearest 0.3 meter per second by observing floating debris; and substrate composition was determined from sonar imagery at the sampling sites. River discharge in cubic feet per second (cfs) was recorded from the Sacramento River gage at Colusa for the Tisdale Reach and at the Butte City gage for the Colusa Reach (California Data Exchange Center 2023). Four egg mats were initially deployed at each site, however; several egg mats were lost over the duration of the survey due to burial by a mobile bedload of sand and fine sediment.

***Tisdale Reach*.** Two sites were selected for egg mat sampling within the Knights Landing reach in 2023; TIS-1 at rkm 203.1, and TIS-2 at rkm 189.7. (**Figure 1**). Sampling was initiated on 18 April and terminated 25 May for a period of seven days. A series of pulse flow releases from Keswick Reservoir beginning 21 April increased flows to over 13,000 cfs which resulted in the egg mats becoming buried by sand and sediment to a point where they could not be retrieved and the therefore the survey was terminated.

Colusa Reach. Three sites were selected for egg mat sampling within the Colusa reach in 2022, COL-3 at rkm 244.3, COL-2 at rkm 247.6 and COL-1 at rkm 250.8 (**Figure 2**). Sampling was initiated on 14 April and terminated 25 April for a period of nine days. Only one mat was deployed at site COL-1. Upon deployment, the mat and buoy drifted downstream in the swift current, and the buoy remained completely submerged and was not visible from the surface. No further sampling was conducted at site COL-1 due to swift currents which would have likely resulted in further loss of sampling equipment or extremely difficult egg mat deployment and retrievals. A series of pulse flow releases from Keswick Reservoir beginning 21 April increased flows to over 13,000 cfs which resulted in the egg mats becoming buried by sand and sediment to a point where they could not be retrieved and therefore the survey was terminated.

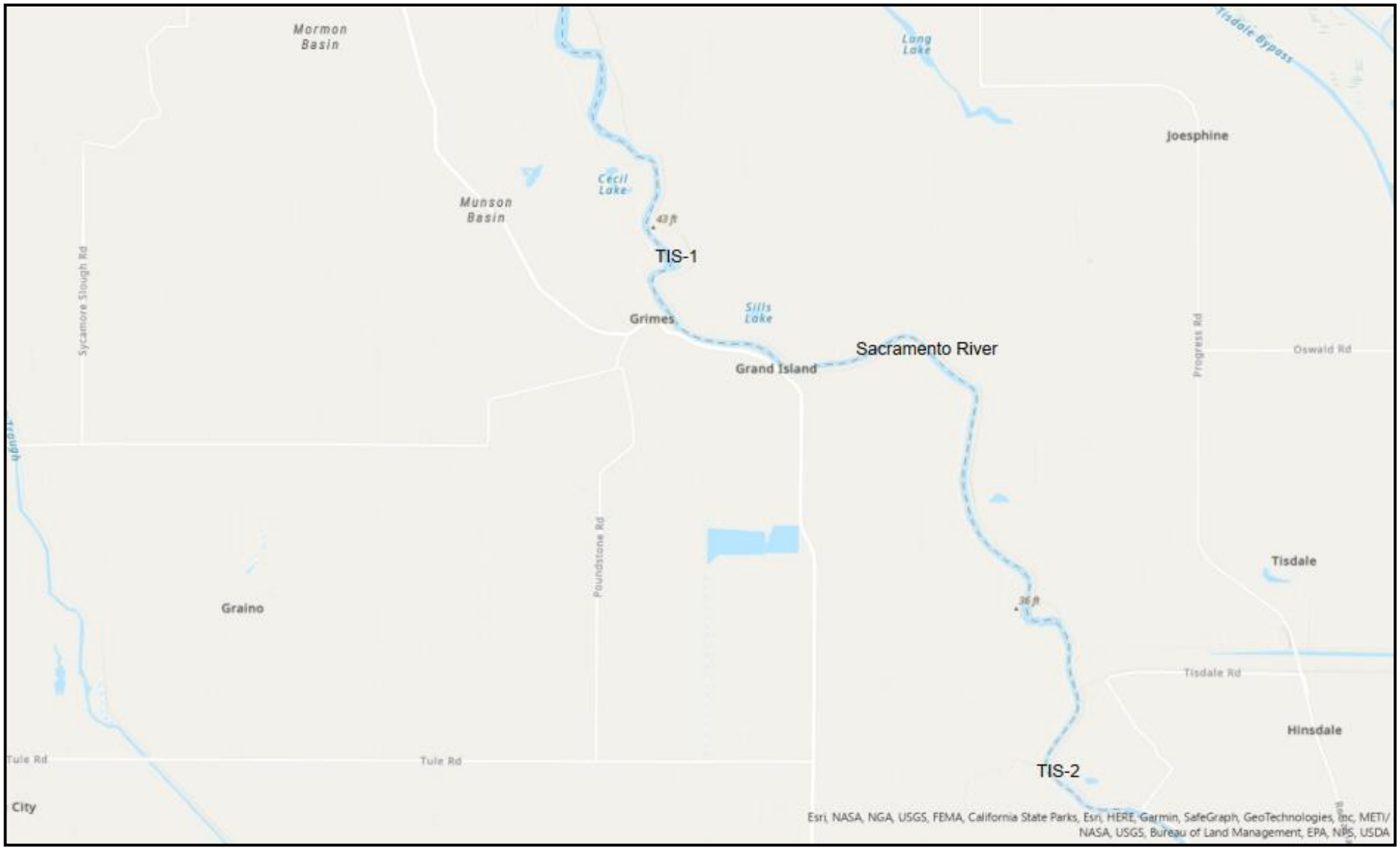

Figure 1. Sacramento River - Tisdale Reach 2023 sturgeon spawning survey sampling sites.

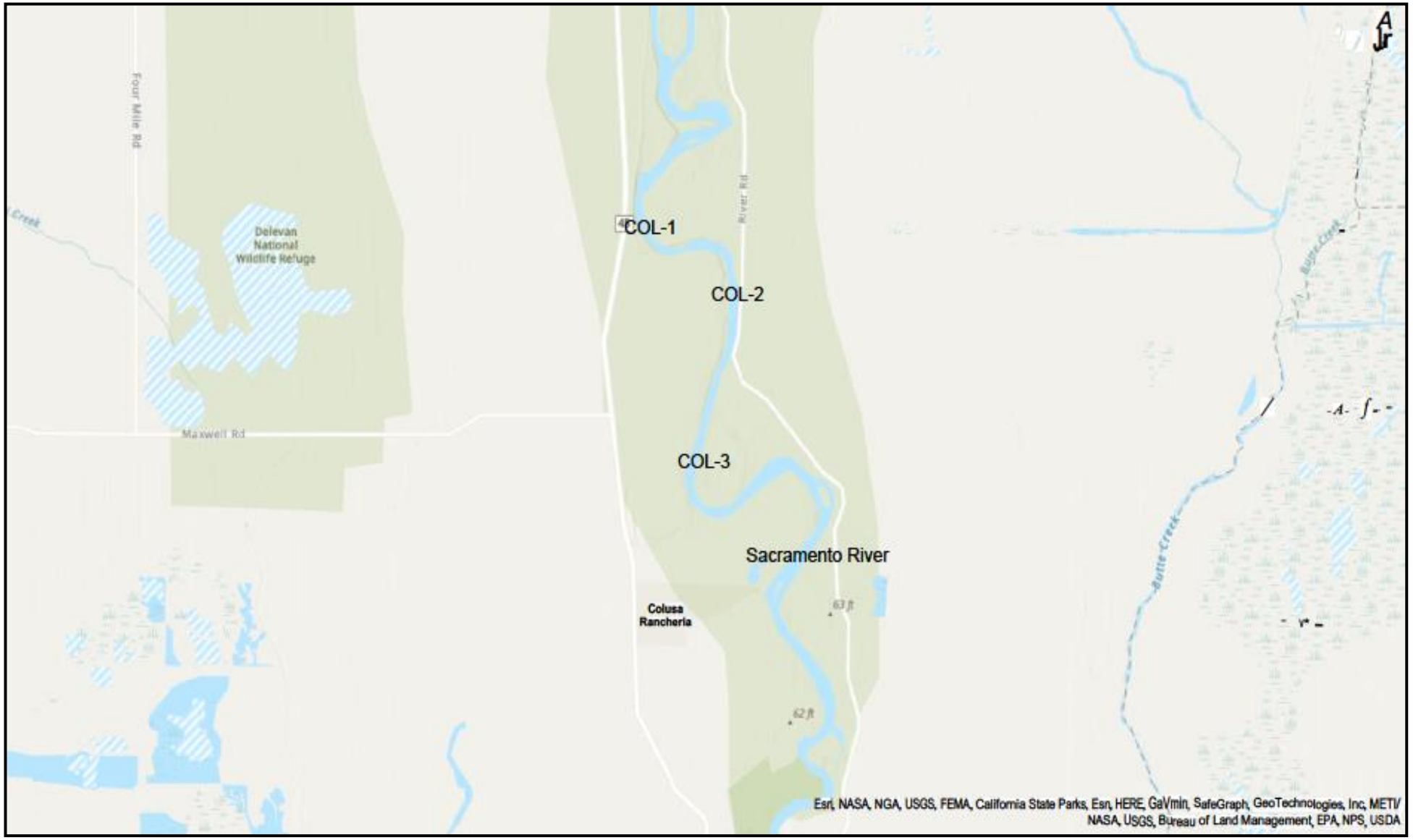

Figure 2. Sacramento River - Colusa Reach 2023 sturgeon spawning survey sampling sites.

Egg mats were retrieved every three to four days over the duration of the sampling period. Retrieval was conducted by using a boat hook or gaff to secure the buoy line and then slowly hauling the egg mat to the surface to avoid dislodging any attached sturgeon eggs. Once the egg mats were hauled on board, two crew members conducted a thorough visual inspection for sturgeon eggs attached to the furnace filter material and mat frame. Both sides of each mat were checked, and debris such as sticks, leaves, and cocklebur seeds were removed from the mats prior to re-deployment. Any sturgeon eggs found on the mats were enumerated and placed in Whirl-Pak® plastic bags containing 70 percent isopropanol labelled with the site code, date collected, and number of eggs vouchered. Observations of other fish species eggs or aquatic organisms were also recorded.

A dissecting microscope at 20-30x power was used to determine species-level identification of any eggs collected using the *Dichotomous Key to Fish Eggs of the Sacramento-San Joaquin River Delta* (Reyes, 2011), and embryonic development of sturgeon eggs was determined based on the work of Wang *et. Al*. (1985) and Colombo *et. Al*. (2007). Egg diameters were measured to the nearest 0.01 mm using a digital caliper. Average water temperature between deployment and retrieval dates was used to calculate degree hours over 10° C, which is the minimum reported temperature for sturgeon egg mitosis (Shelton et. al., 1997). Degree hours were then extrapolated to estimate approximate spawning dates and times.

Results

Tisdale Reach. No white sturgeon eggs were collected from egg mats deployed in the Tisdale Reach during the 2023 survey season. Egg mats deployed at TIS-2 on 18 April were not found on 21 or 25 April 2023. The buoys did not remain on the surface after the 18 April deployment date, although the buoy line lengths were over twice the water depth at the site. The surface current did not appear to be more than three feet per second, however; the current at mid-depth or the bottom may have been swift enough to prevent the buoys from reaching the surface. The mats deployed at TIS-1 were retrieved, checked for sturgeon eggs, and redeployed on 21 April, however; although the buoys were located and hauled aboard on 25 April, the mats could not be retrieved as they were buried in sand and fine sediment. Sacramento River flows began to increase on 25 April due to pulse flow releases from Shasta and Keswick reservoirs, and therefore it was decided to terminate the survey in the Tisdale reach.

No other fish species eggs were collected on mats deployed in the Tisdale reach. Benthic macroinvertebrates commonly observed on the mats included Asian clams (*Corbicula fluminea*), amphipods (*Corophium* sp.), may fly larvae in the families Baetidae and Heptageniidae, and caddisfly larvae in the family Hydropsychidae.

Substrates within the Tisdale reach sites consist of mostly sand and fine sediment. Cobble or concrete revetment are present along the banks and nearshore inundated areas of the sites. Estimated surface velocities ranged from two to three feet per second. Deployment and retrieval dates and environmental parameters are presented in **Table 2.** Sacramento River flows at Colusa and water temperature measured during site visits are presented in **Figure 3.**

Colusa Reach. Sixteen white sturgeon eggs were collected from egg mats deployed in the Colusa Reach during the 2023 survey season at site COL-2 on 18 April from mats deployed on 14 April at a depth of 24 feet. Only six were measured for diameter, and of the six, only four could be assessed for developmental staging as the remaining 10 eggs appeared to have damaged chorions and were swollen. In addition, the embryos appeared to be damaged or degraded. It is possible that the use of isopropanol as a preservative caused the eggs to swell and damaged the chorions and embryos within. Egg diameters for the six measured eggs ranged from 2.93 mm to 3.91 mm (**Table 2**), with a mean diameter of 3.49 mm, which is within the diameter range of 3.2 to 4.0 mm for white sturgeon eggs reported by Van Eenennaam *et. al.* (2006). Based on the work of Colombo *et. al*. (2007), the embryonic stage of the eggs collected from site COL-2 on 18 April ranged from stage 15 (2/3 of embryo covered by animal material) to stage 26 (heart rudiment forming, tail rudiment separating) when they were preserved in 70 percent isopropanol. Water temperatures during the period between when egg mats were last deployed prior to egg collection and when the eggs were collected ranged from 12.2° C on 14 April to 13.9° C on 18 April, with an average calculated temperature of 13.0° C. Extrapolation of developmental staging data for white sturgeon eggs reported by Wang et. al. (1985) at a temperature of 13.0° C corresponds to 35 to 84 hours from fertilization to reach stages 13 through 26. Given that completion of oviposition in white sturgeon may take over 20 hours (Van Eenennaam *et. al.* 2006), it is likely that the white sturgeon eggs collected on 18 April at site COL-2 were from spawning events which occurred between 14 April at 2200 and 17 April at 0300.

No other fish species eggs were observed on the egg mats. Benthic macroinvertebrates commonly found on the mats included Asian clams, mayfly larvae in the families Baetidae and Heptageniidae, and caddisfly larvae in the family Hydropsychidae. Substrates at the two Colusa reach sites consist of mainly of gravel and coarse sand, and some small cobble. Some cobble revetment is present along the banks and nearshore inundated areas of the sites. Estimated surface velocities during the survey period ranged from one to four feet per second. Deployment and retrieval dates and environmental parameters are presented in **Table 2.** Sacramento River flows at the Butte City gaging station and water temperatures measured during site visits are presented in **Figure 4. Figure 5** is a photograph of white sturgeon eggs collected from site COL-2 on 18 April 2023. Sacramento River flows at Butte City, the nearest gaging

station upstream of the Colusa sites, ranged from a high of 14,210 on 14 April to a low of 10,911 cfs on 21 April. Flows began to increase on 22 April in response to a pulse flow release from Keswick Dam. Water temperatures within the Colusa Reach over the duration of the survey ranged from 12.2 °C on 14 April to 16.1 °C on 25 April.

Table 1. 2023 Sacramento River sturgeon spawning survey egg mat deployment and retrieval dates, water temperatures, deployment depth range, and number of sturgeon eggs collected.

Site code	Deployment date	Temperature (° C)	Deployment depth range (ft)	Retrieval date	Temperature (° C)	Sturgeon eggs (n)
TIS-1	4/18	13.9	17-20	4/21	15.0	None
TIS-2	Could not find marker buoys after deployment; current velocity ~ four feet per second					
TIS-1	4/21	15.0	16-19	Could not retrieve on 4/25; buried		
TIS-2	Could not find marker buoys after deployment; current velocity ~ four feet per second					
TIS-1	Could not retrieve on 4/25; not redeployed					
TIS-2	Could not find marker buoys after deployment; current velocity ~ four feet per second					
COL-1	4/14; 11:36	12.2	21	One mat deployed, could not find		
COL-2	4/14; 11:53	12.2	20-24	4/18; 14:15	13.9	16
COL-3	4/14; 12:40	12.2	14-23	4/18; 15:00	13.9	None
COL-1	Could not find marker buoy on 4/18; current velocity ~ five feet per second					
COL-2	4/18; 14:20	13.9	20-23	4/21; 10:40	13.9	None
COL-3	4/18; 15:10	13.9	13-18	4/21; 11:15	13.9	None
COL-1	Could not find marker buoy on 4/21; current velocity ~ five feet per second					
COL-2	4/21; 10:50	13.9	20-21	4/25; 11:00	16.1	None
COL-3	4/21; 11:30	13.9	13-18	4/25; 11:20	16.1	None

Table 2. White sturgeon egg collection site, date collected, egg diameter, egg stage number, and egg stage description.

Site	Date collected	Egg number	Diameter (mm)	Stage number	Stage description
COL-2	4/18	1	3.91	Not determined	
COL-2	4/18	2	3.53	17	Small yolk plug
COL-2	4/18	3	3.58	15	2/3 of embryo covered by animal material
COL-2	4/18	4	3.84	26	heart rudiment forming, tail rudiment separating
COL-2	4/18	5	3.18	16	Large yolk plug
COL-2	4/18	6	2.93	Not determined	

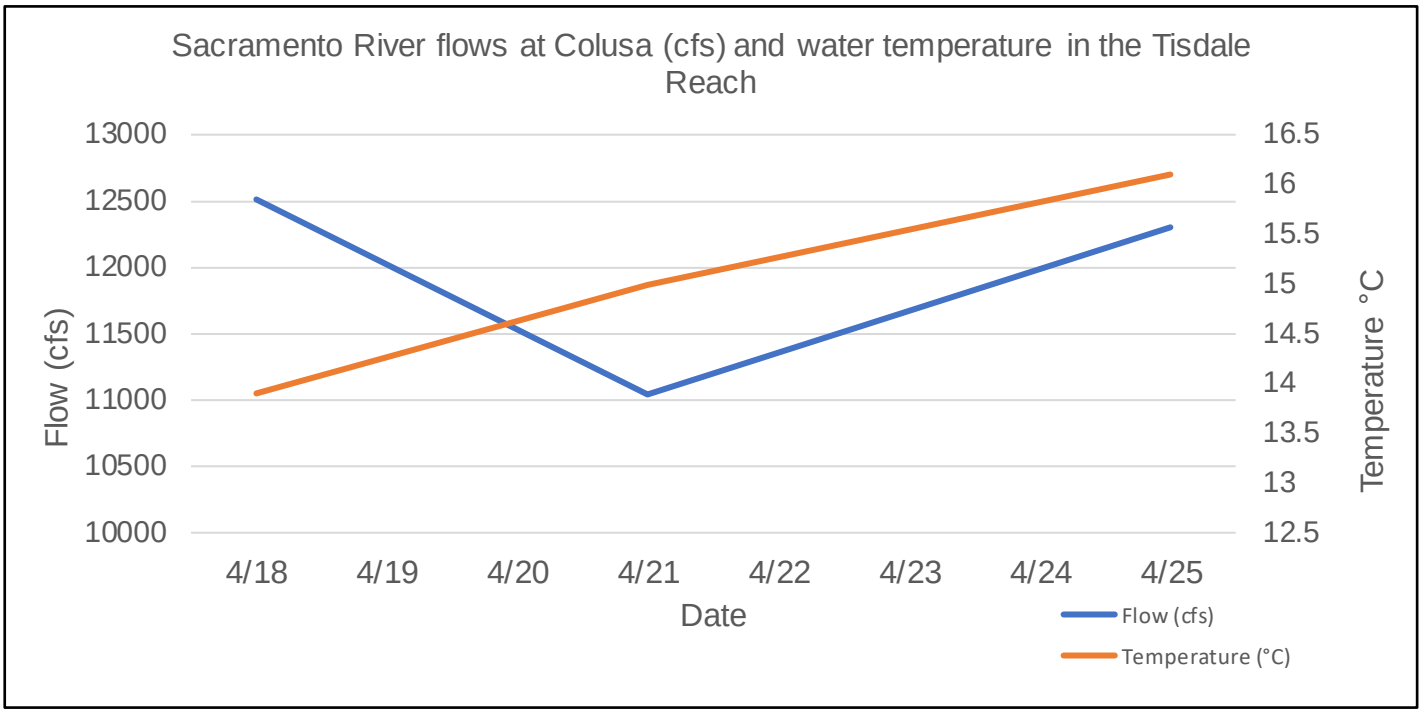

Figure 3. Sacramento River flow at the Colusa gaging station and water temperature within the Tisdale Reach during the 2023 sturgeon spawning survey.

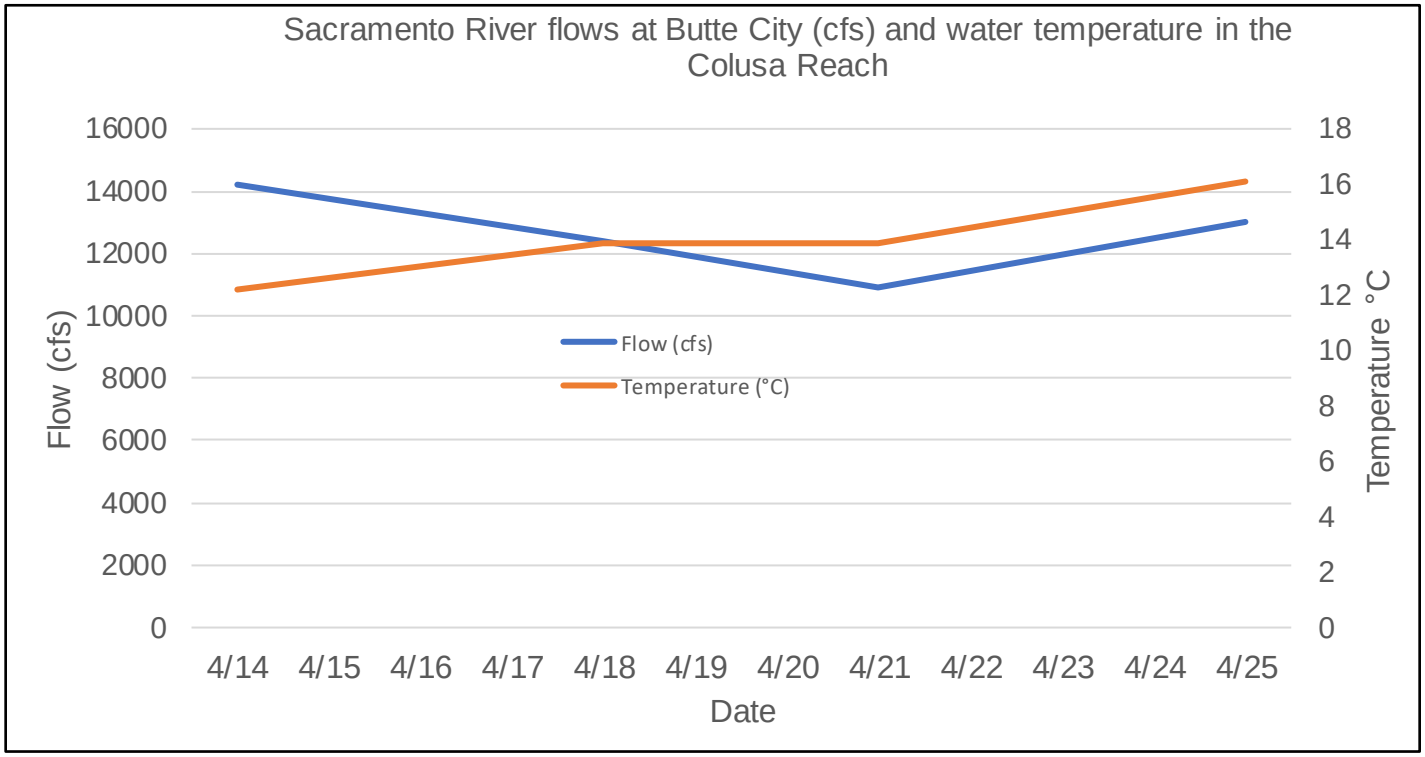

Figure 4. Sacramento River flow at the Butte City gaging station and water temperature in the Colusa Reach during the 2022 sturgeon spawning survey. White sturgeon eggs were collected at site COL-2 on 18 April.

Figure 5. White sturgeon eggs on an egg mat retrieved 18 April 2023 from site COL-2. Six eggs are visible in the lower left corner and one in the upper left corner. All eggs are mostly covered in sand and fine sediment.

Discussion

The 2023 Sacramento River sturgeon spawning survey was the third consecutive year that white sturgeon spawning was documented in the Colusa Reach at site COL-2 and is approximately 3.8 km downstream from the site COL-1 where white sturgeon eggs were collected during the 2022 spawning survey and by Schaffter (1997) in 1992. The timing of the 2023 spawning events were one to two days later in those documented in 2022 and were within temporal range found in 1992 by Schaffter, when 32 white sturgeon eggs were collected from the Colusa Reach between 24 March and 21 April. Water temperatures in the Colusa reach during spawning events ranged from 12.2° C to 13.9° C, which were slightly lower than 14.0° C to 14.3° C water temperatures observed during the 2022 spawning events (CDFW 2022). Schaffter (1997) found that white sturgeon spawning usually occurs on a receding hydrograph after recent flow increases; the 2023 spawning events occurred during a fairly long receding hydrograph characterized by a peak flow of 90,256 cfs on 16 March 2023. Ideally, the 2023 spawning should have been initiated earlier in the season, however; high flows and the associated mobile bedload of sand and sediment made it impractical to deploy and retrieve egg mats without modifications such as adding anchors to the mat frames and using a larger vessel with a power driven winch or davit to assist in mat retrieval. At least one white sturgeon spawning event occurred in the Sacramento River prior to the initiation of the 2023 spawning survey, as CDFW Region 3 staff captured a yolk sac stage larvae in the 20-mm midwater trawl survey near Rio Vista during the week of 20 March.

Documentation of the spatial and temporal parameters of white sturgeon spawning in the Sacramento River is important for several reasons. As the California white sturgeon numbers continue to decline (Blackburn, 2018), a number of conservation measures should be considered to maximize spawning success and recruitment to the juvenile life stage. Substrate composition is likely the most important factor influencing the survival of sturgeon eggs and developing larvae. Large gravel and boulder substrate can increase survival of eggs and developing larvae by providing more suitable interstitial spaces which should decrease predation and increase available oxygen. Successful recruitment of Age-0 juvenile white sturgeon in reaches of the Columbia River is greatest in reaches dominated by gravel and cobble substrates (Hatten *et. al.* 2018). McAdam (2011) found that in laboratory flume studies, one to 15-day post-hatch (dph) white sturgeon larvae hid within three to twelve seconds in interstitial spaces provided

by large gravel and cobble substrates and were far less likely to be consumed by prickly sculpin (*Cottus asper*) and coastrange sculpin *and* (*C. aleuticus*), both of which are known to prey upon sculpin eggs and larvae. The drift of early-stage white sturgeon larvae has been well documented in the Sacramento River, particularly during years with high outflow, when early-stage white sturgeon larvae were collected as far downstream as Rio Vista (CDFW unpublished data). Drift of this spatial magnitude is likely a result of spawning events occurring in river reaches with little or no interstitial habitat where eggs and larvae are carried miles downstream and are more susceptible to predation. One to 15 dph larvae that were released in flumes with sand substrates drifted toward the downstream end of the flume and were much more likely to be preyed upon by sculpin (McAdam, 2011).

While the substrate in the Colusa reach may be suitable for successful recruitment, substrate composition in the Sacramento River downstream of Colusa is dominated by sand and fine sediment and does not provide interstitial spaces for oviposited eggs to collect, and likely results in higher predation rates of eggs and developing larvae. Fine sediment adhering to the egg membrane may reduce the oxygen diffusion to the developing embryo and could result in egg mortality or delayed hatching.

While there is some cobble and gravel sand in the Colusa Reach, spawning habitat could be further enhanced by the addition of small boulders and additional cobbles. Spawning habitat within the Tisdale reach and potential spawning sites downstream of Tisdale could be enhanced by the addition of large gravel, cobble and small boulder substrates. However, large substrate augmentation would likely need to be conducted on an annual basis due to the mobile bedload of sand and fine sediment within the lower reaches of the Sacramento River. Spawning habitat enhancement through the addition of large substrates such as the as cobble and boulder to known or potential sturgeon spawning habitat has been shown to be beneficial for lake sturgeon (*Acipenser fulvescens*) in the Detroit River. Lake sturgeon spawning monitoring surveys at an artificial reef of cobblestone placed in the Detroit River resulted in the collection of lake sturgeon eggs where Lake sturgeon spawning had not been documented since the removal of large substrates during shipping channel construction in the 1900s (Fisher, 2018). In the Des Prairies River, a nearly five-fold increase in drifting Lake sturgeon larvae was observed for multiple years after a spawning substrate augmentation project was completed at a known spawning site (Dumont et al., 2011).

Seasonal closures of recreational fishing in known white sturgeon spawning reaches of the Sacramento River system should also be considered as a measure to increase spawning success, and is currently under consideration. Catch and release of white sturgeon on spawning grounds or during spawning migration may result in abortion of spawning. Radio telemetry data suggest that nearly one-half of white sturgeon captured

on set lines in the Sacramento River near Freeport in 1991 and 1992 appeared to abort their spawning migration (Schaffter, 1997). Washington's sport fishing regulations include recreational white sturgeon fishing closures for catch and release fishing in spawning reaches of the Columbia River during spawning and post-spawning periods to minimize stress which may result in aborted spawning or delayed mortality from excessive handling associated with catch and release angling.

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