**State of California**
**Department of Fish and Wildlife**

# M e m o r a n d u m

**Date:** July 18, 2022

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**Subject: 2021 Sacramento River Sturgeon Spawning Study**

## Purpose

The purpose of this report is to document findings regarding the 2021 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). 2021 is the fourth 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 upon contact. 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 did not collect any sturgeon eggs. 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).

## 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 either dual frequency identification sonar (DIDSON) or 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 (California Data Exchange Center 2021). Four egg mats were initially deployed at each site, however; several egg mats were lost over the duration of the survey due to vandalism or burial by a mobile bedload of sand or fine sediment and were not replaced.

Egg mats were retrieved every three to seven 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 by 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 ethanol 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). 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 used to calculate an approximate spawning date and time.

*Knights Landing Reach*. Three sites were selected for egg mat sampling within the Knights Landing reach in 2021, KL-1 at rkm 179.0, KL-2 at rkm 170.6, and KL-3 at rkm 161.1. (**Figure 1**). Sampling was initiated 16 February and terminated 7 May for a period of 80 days.

*Colusa Reach.* Three sites were selected for egg mat sampling within the Colusa reach in 2021, COL-3 at rkm 243.5, COL-2 at rkm 247.6 and COL-1 at rkm 249.0 (**Figure 2**). Sampling was initiated 18 February and terminated 7 May for a period of 78 days.

## Results

*Knights Landing Reach.* No sturgeon eggs were collected from egg mats deployed in the Knights Landing Reach during the 2021 survey season, and no other fish eggs were observed on the mats. Benthic macroinvertebrates commonly observed on the mats included Asian clams (*Corbicula fluminea*), mayfly larvae in the families Baetidae and Heptageniidae, and caddisfly larvae in the family Glossosomatidae. Water temperatures during the survey period ranged from 10.3° C on 16 February to 20.7° C on 7 May. Sacramento River flows at Wilkins Slough, the nearest gaging station upstream of the Knights Landing sites, ranged from 8,660 cubic feet per second (cfs) on 17 February to 4,013 cfs on 1 May. Substrates within the Knights Landing reach sites consist of mostly sand and fine sediment. Cobble and concrete revetment are present along the banks and nearshore inundated areas of the sites. Estimated surface velocities ranged from one to three feet per second. Several egg mats were lost as a result of vandalism, or burial by a mobile bedload of sand or fine sediment and were not replaced over the duration of the survey. Water temperature and deployment depths were not recorded for several dates due to a broken sonar transducer mount. Deployment and retrieval dates and environmental parameters are presented in **Table 1.** Sacramento River flows for Wilkins Slough, the nearest gaging station upstream of the Knights Landing sites, are presented in **Figure 3.**

*Colusa Reach.* One white sturgeon egg was collected on 16 April 2021 at approximately 14:00 from an egg mat deployed at site COL-1 on 13 April 2021 at 13:50 at a depth of 12 feet. Based on the work of Colombo et al (2007), the embryonic stage of the egg was 16 (large yolk plug) when it was preserved in 70 percent ethanol. The water temperature dropped slightly from 16.9° C when the mat was deployed on 13 April to 16.0° C when the mat was retrieved on 16 April. The average temperature over this 72-hour period was calculated at 16.4° C which for white sturgeon corresponds to 136 hours from fertilization to reach stage 16 embryonic development. Based on the embryo stage of 16 for the single egg, spawning and fertilization of the egg occurred approximately 34 hours after the mat was deployed, which suggests a spawning date and time of 14 April at 23:50. Sacramento River flows at Butte City, the nearest gaging station upstream of the Colusa sites, dropped slightly from 5,132 cfs on 13 April to 4,898 cfs on 16 April.

Benthic macroinvertebrates commonly observed on the mats included signal crayfish (*Pacifastacus leniusculus*), Asian clams, may fly larvae in the families Baetidae and Heptageniidae, and caddisfly larvae in the family Glossosomatidae. Water temperatures during the survey period ranged from 11.1° C on 19 March to 19.4° C on 26 April and 7 May. Substrates at the three Colusa reach sites consist of mainly of gravel and coarse sand, and some small cobble. Cobble revetment is present along the banks and nearshore inundated areas of the sites. Estimated surface velocities ranged from one to four feet per second. Deployment and retrieval dates and environmental parameters are presented in **Table 1.** Sacramento River flows for Butte City, the nearest gaging station upstream of the Colusa sites, are presented in **Figure 4.**

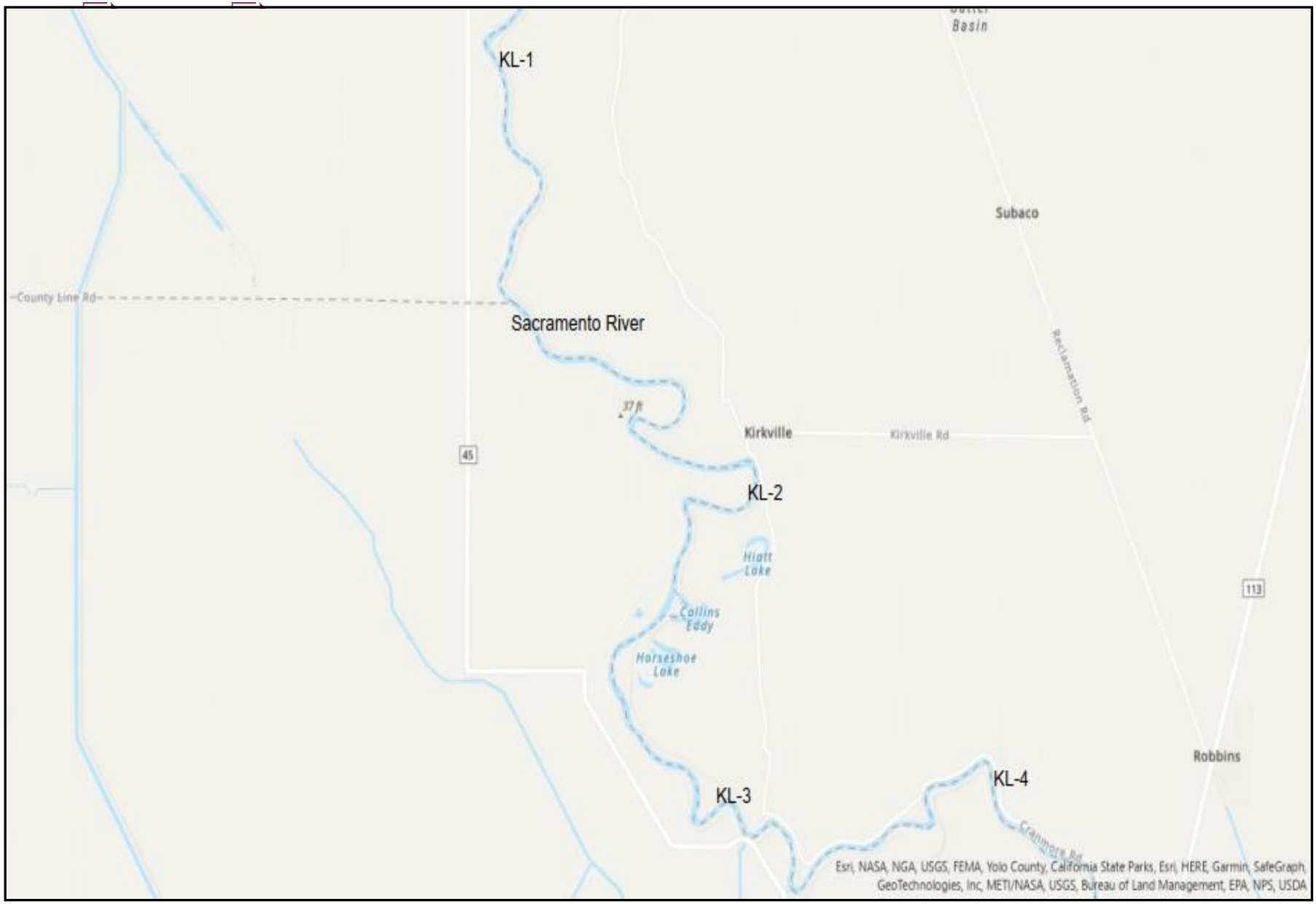


**Figure 1. Sacramento River - Knights Landing Reach 2021 sturgeon spawning survey sampling sites.**

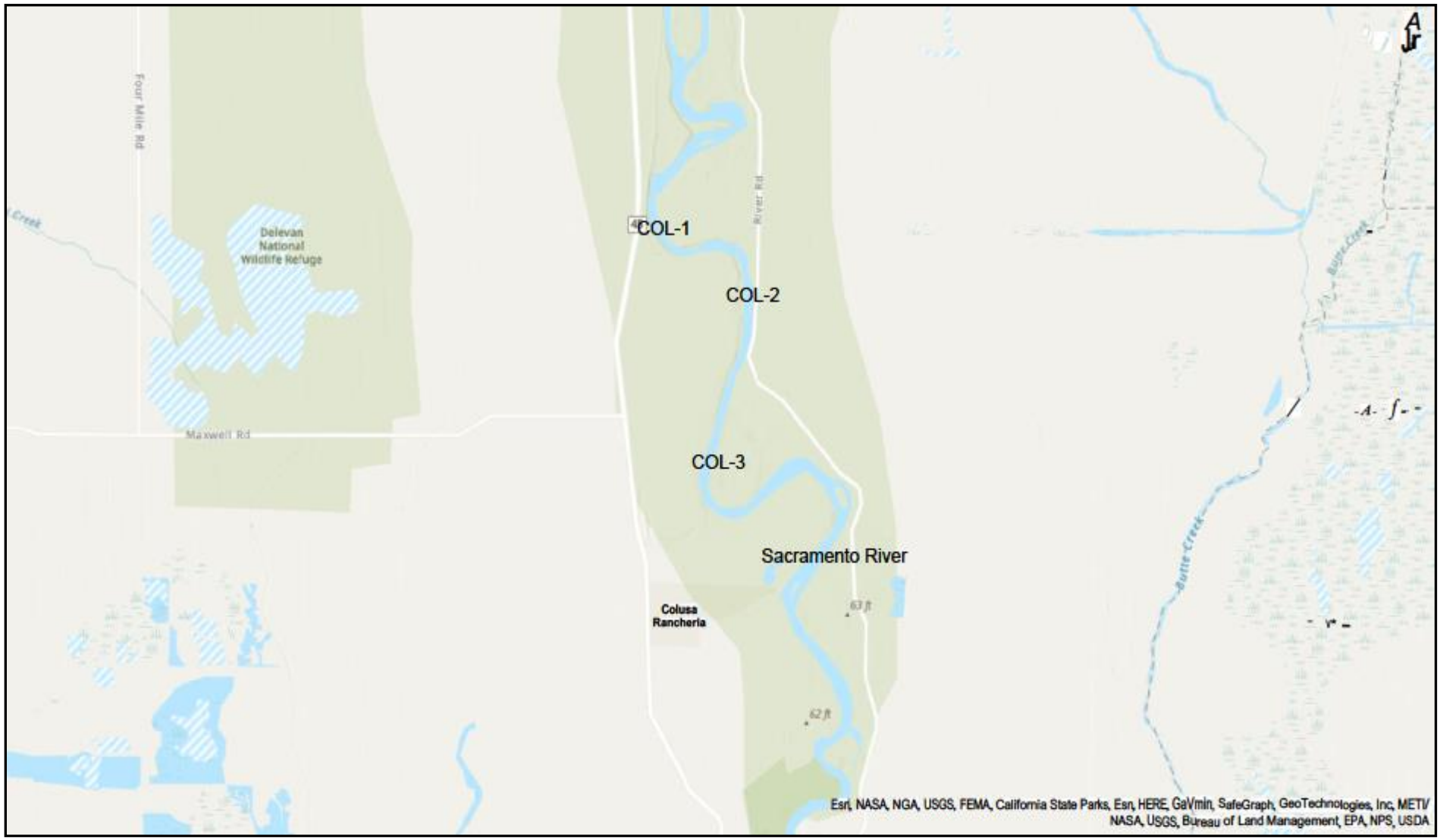


**Figure 2. Sacramento River - Colusa Reach, 2021 sturgeon spawning survey sampling sites.**

**Table 1. 2021 Sacramento River sturgeon spawning survey site sampling dates, water temperatures, deployment depth range, and number of sturgeon eggs collected.**

| Site code | Deployment date | Temperature (° F) | Deployment depth range (ft) | Retrieval date | Temperature (° F) | Sturgeon eggs (n) |
|---|---|---|---|---|---|---|
| KL-1 | 2/16 | 10.3 | Not recorded | 2/19 | 10.4 | 0 |
| KL-2 | | | | | | 0 |
| KL-3 | | | | | | 0 |
| KL-1 | 2/19 | 10.4 | 17-20 | 2/23 | 11.5 | 0 |
| KL-2 | | | 18-20 | | | 0 |
| KL-3 | | | 16-28 | | | 0 |
| KL-1 | 2/23 | 11.5 | 17/22 | 2/26 | | |
| KL-2 | | | 20-23 | | | |
| KL-3 | | | Not recorded | | | |
| KL-1 | 2/26 | 11.6 | Not recorded | 3/2 | 11.7 | 0 |
| KL-2 | | | Not recorded | | | 0 |
| KL-3 | | | Not recorded | | | 0 |
| | | | | | | |
| KL-1 | 3/2 | 11.7 | 17-24 | 3/5 | 11.9 | 0 |
| KL-2 | | | 12-38 | | | 0 |
| KL-3 | | | 12 (all) | | | 0 |
| KL-1 | 3/5 | 11.9 | 16-23 | 3/9 | 12.7 | 0 |
| KL-2 | | | 26 (all) | | | 0 |
| KL-3 | | | 13-16 | | | 0 |
| KL-1 | 3/9 | 12.7 | 18-22 | 3/12 | Not recorded | 0 |
| KL-2 | | | 13-18 | | | 0 |
| KL-3 | | | 15-16 | | | 0 |
| KL-1 | 3/12 | Not recorded | 15-24 | 3/16 | Not recorded | 0 |
| KL-2 | | | 14-27 | | | 0 |
| KL-3 | | | 10-13 | 3/19 | | 0 |
| KL-1 | 3/16 | | Not recorded | | | 0 |
| KL-2 | | | | | | 0 |
| KL-3 | 3/19 | Not recorded | Not recorded | 3/22 | 12.6 | 0 |
| KL-1 | | | Not recorded | | | 0 |
| KL-2 | | | Not recorded | | | 0 |
| KL-3 | | | Not recorded | | | 0 |
| KL-1 | 3/22 | 12.6 | Not recorded | 3/26 | Not recorded | 0 |
| KL-2 | | | Not recorded | | | 0 |
| KL-3 | | | Not recorded | | | 0 |
| KL-1 | 3/26 | Not recorded | 15-17 | 3/31 | 16.0 | 0 |

| Site code | Deployment date | Temperature (° F) | Deployment depth range (ft) | Retrieval date | Temperature (° F) | Sturgeon eggs (n) |
|---|---|---|---|---|---|---|
| KL-2 | | | 20 (all) | | | 0 |
| KL-3 | | | 12-13 | | | 0 |
| KL-1 | 3/31 | 60.8 | 15-16 | 4/2 | Not recorded | 0 |
| KL-2 | | | 17 (all) | | | 0 |
| KL-3 | | | 12-13 | | | 0 |
| KL-1 | 4/2 | Not recorded | 13-20 | 4/6 | Not recorded | 0 |
| KL-2 | | | 13 (all) | | | 0 |
| KL-3 | | | 12 (all) | | | 0 |
| KL-1 | 4/6 | Not recorded | 13-19 | 4/9 | 17.1 | 0 |
| KL-2 | | | 16-18 | | | 0 |
| KL-3 | | | 11-13 | | | 0 |
| KL-1 | 4/9 | 17.1 | 11-22 | 4/13 | 17.4 | 0 |
| KL-2 | | | 13-14 | | | 0 |
| KL-3 | | | 11-12 | | | 0 |
| KL-1 | 4/13 | 17.2 | 13-18 | 4/16 | 17.2 | 0 |
| KL-2 | | | 11-13 | | | 0 |
| KL-3 | | | 11-12 | | | 0 |
| KL-1 | 4/16 | 17.2 | 13-18 | 4/20 | 18.7 | 0 |
| KL-2 | | | 11-17 | | | 0 |
| KL-3 | | | 10-12 | | | 0 |
| KL-1 | 4/20 | 18.7 | 11-18 | 4/23 | 18.6 | 0 |
| KL-2 | | | 16-20 | | | 0 |
| KL-3 | | | 10-12 | | | 0 |
| KL-1 | 4/23 | 18.6 | 13-18 | 4/30 | 18.5 | 0 |
| KL-2 | | | 15-17 | | | 0 |
| KL-3 | | | 10-12 | | | 0 |
| KL-1 | 4/30 | 18.5 | Not recorded | 5/7 | 20.7 | 0 |
| KL-2 | | | Not recorded | | | 0 |
| KL-3 | | | Not recorded | | | 0 |
| COL-1 | 2/18 | 9.4 | 19-20 | 2/25 | 9.9 | 0 |
| COL-2 | | | 17-21 | | | 0 |
| COL-1 | 2/25 | 9.9 | 16-18 | 3/2 | 10.7 | 0 |
| COL-2 | | | 15-18 | | | 0 |
| COL-3 | | | 15-17 | | | 0 |
| COL-1 | 3/2 | 10.7 | 11-18 | 3/5 | 10.7 | 0 |
| COL-2 | | | 10-18 | | | 0 |
| COL-3 | | | 18-20 | | | 0 |
| COL-1 | 3/5 | 11.0 | 10-18 | 3/9 | 11.2 | 0 |

| Site code | Deployment date | Temperature (° F) | Deployment depth range (ft) | Retrieval date | Temperature (° F) | Sturgeon eggs (n) |
|---|---|---|---|---|---|---|
| COL-2 | | | 9-20 | | | 0 |
| COL-3 | | | 19-20 | | | 0 |
| COL-1 | 3/9 | 11.2 | 9-19 | 3/12 | 10.3 | 0 |
| COL-2 | | | 14-21 | | | 0 |
| COL-3 | | | 17-20 | | | 0 |
| COL-1 | 3/12 | 10.3 | 9-21 | 3/16 | 10.4 | 0 |
| COL-2 | | | 16-22 | | | 0 |
| COL-3 | | | 17-22 | | | 0 |
| COL-1 | 3/16 | 10.4 | 12-21 | 3/19 | 10.8 | 0 |
| COL-2 | | | 18-23 | | | 0 |
| COL-3 | | | 19-20 | | | 0 |
| COL-1 | 3/19 | 10.8 | 10-20 | 3/23 | 12.0 | 0 |
| COL-2 | | | 18-20 | | | 0 |
| COL-3 | | | 21-22 | | | 0 |
| COL-1 | 3/23 | 12.0 | 10-20 | 3/26 | 12.4 | 0 |
| COL-2 | | | 18-19 | | | 0 |
| COL-3 | | | 22-23 | | | 0 |
| COL-1 | 3/26 | 12.4 | 9-19 | 3/30 | 13.1 | 0 |
| COL-2 | | | 16-18 | | | 0 |
| COL-3 | | | 20 (all) | | | 0 |
| COL-1 | 3/30 | 13.1 | 10-20 | 4/6 | 16.3 | 0 |
| COL-2 | | | Not recorded | | | 0 |
| COL-3 | | | Not recorded | | | 0 |
| COL-1 | 4/6 | 16.3 | 10-19 | 4/13 | 16.9 | 0 |
| COL-2 | | | 15-17 | | | 0 |
| COL-3 | | | 17-21 | | | 0 |
| COL-1 | 4/13 | 16.9 | 10-20 | 4/16 | 16.0 | **1** |
| COL-2 | | | 17-18 | | | 0 |
| COL-3 | | | 18-22 | | | 0 |
| COL-1 | 4/16 | 16.0 | Not recorded | 4/23 | Not recorded | 0 |
| COL-2 | | | Not recorded | | | 0 |
| COL-3 | | | Not recorded | | | 0 |
| COL-1 | 4/23 | Not recorded | 11-19 | 4/27 | 18.2 | 0 |
| COL-2 | | | 11-19 | | | 0 |
| COL-3 | | | 18-19 | | | 0 |
| COL-1 | 4/27 | 18.2 | 11-12 | 4/30 | 19.2 | 0 |
| COL-2 | | | 13-20 | | | 0 |
| COL-3 | | | 17-18 | | | 0 |

| Site code | Deployment date | Temperature (° F) | Deployment depth range (ft) | Retrieval date | Temperature (° F) | Sturgeon eggs (n) |
|---|---|---|---|---|---|---|
| COL-1 | 4/30 | 19.2 | 12-13 | 5/4 | 19.2 | 0 |
| COL-2 | | | 13-18 | | | 0 |
| COL-3 | | | 18-21 | | | 0 |
| COL-1 | 5/4 | 19.2 | 16-19 | 5/7 | 20.4 | 0 |
| COL-2 | | | 10-20 | | | 0 |
| COL-3 | | | 18-21 | | | 0 |

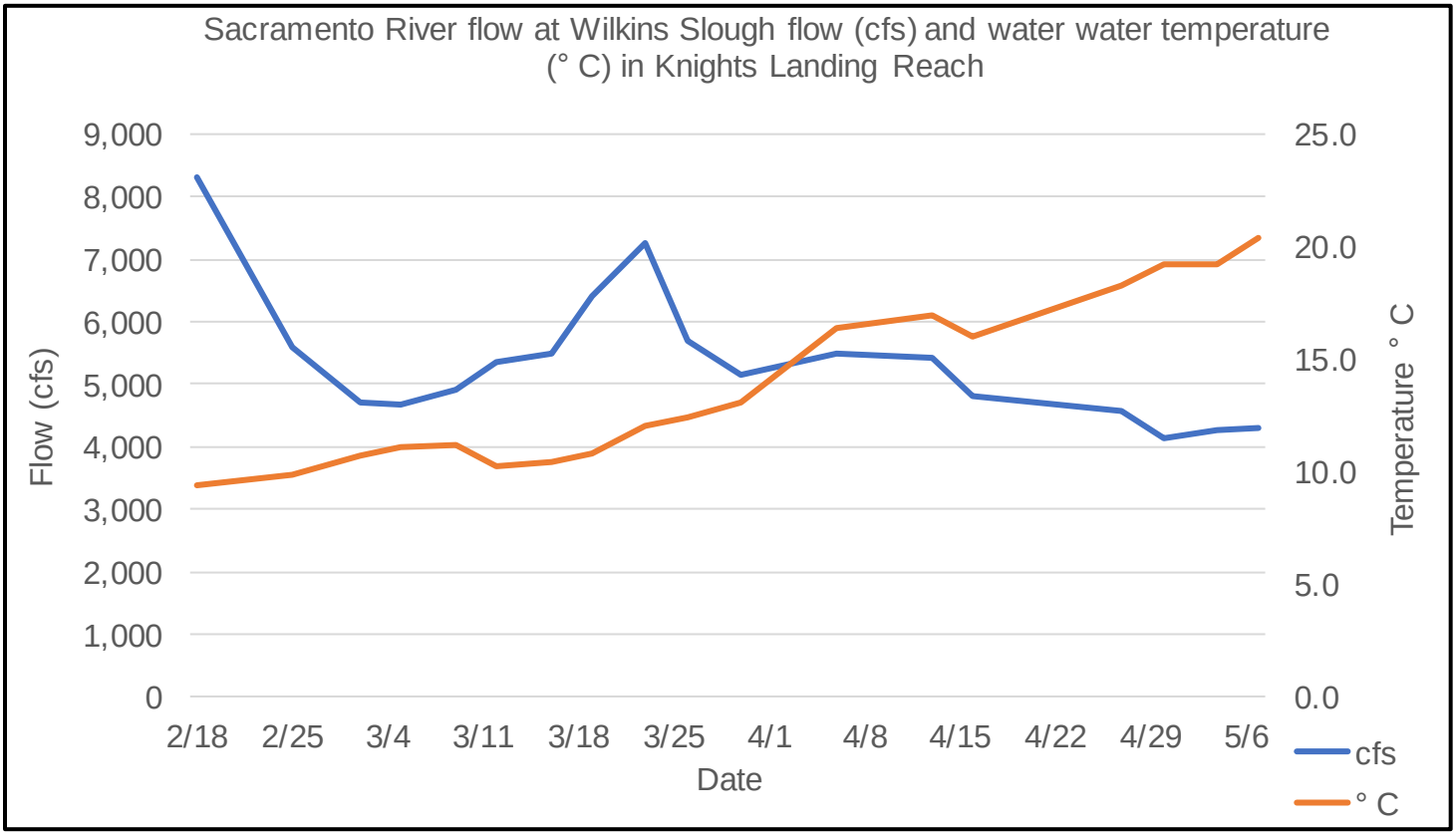


**Figure 3. Sacramento River flows at Wilkins Slough and measured water temperature within the Colusa Reach, 2021 sturgeon spawning survey.**

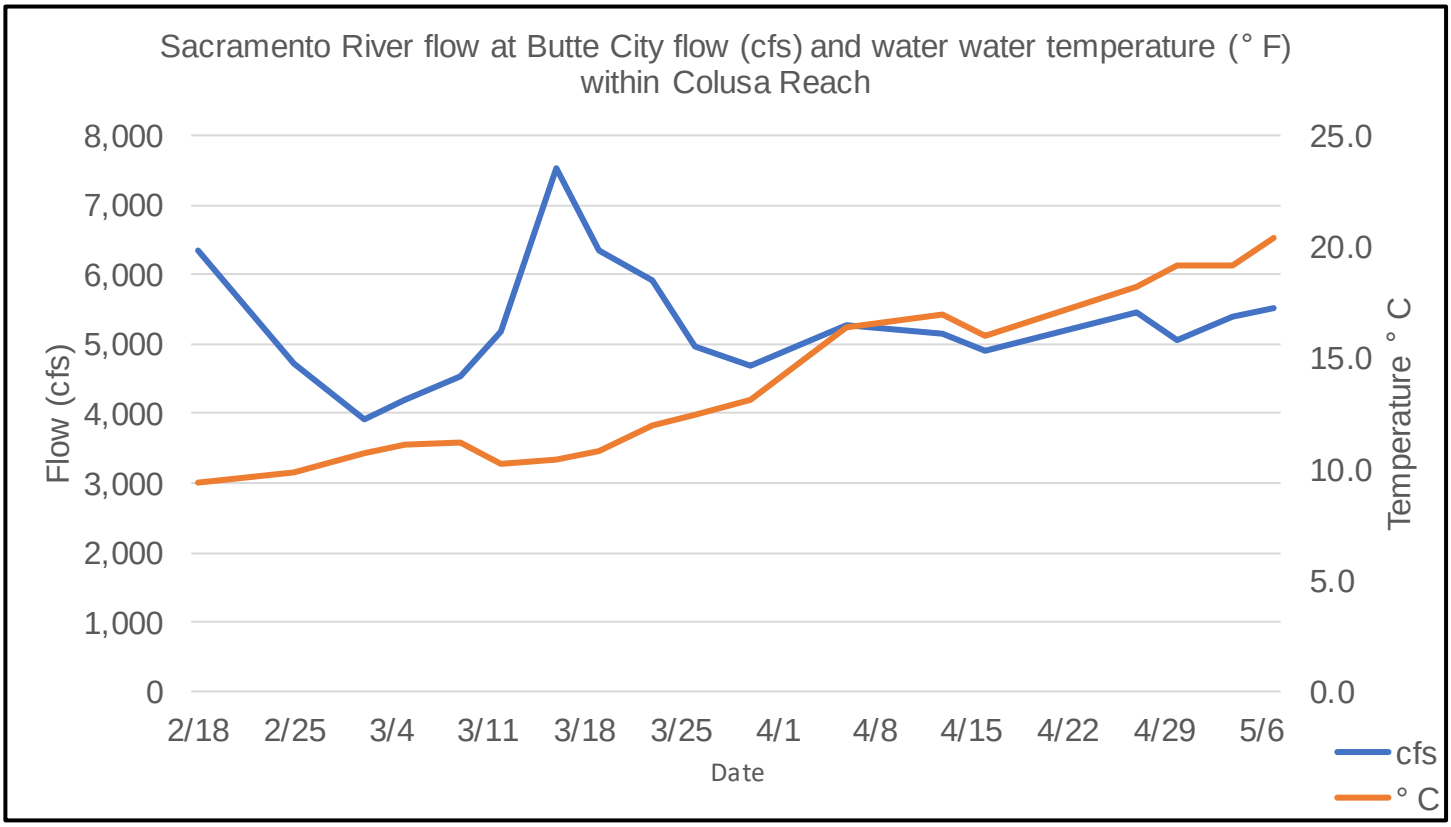


**Figure 4. Sacramento River flows at Butte City and water temperature in the Colusa Reach, 2021 sturgeon spawning survey.**

## Discussion

The 2021 Sacramento River sturgeon spawning survey of Colusa Reach was the first year that white sturgeon spawning was documented by the collection of a single sturgeon egg; prior efforts in 2018 and 2019 to document spawning in the Colusa reach did not result in the collection of any sturgeon eggs. The collection of the egg at site COL-1 (rkm 249.0) is approximately 2.4 km downstream from the site where white sturgeon eggs were collected by Schaffter (2007) in 1992. The timing of the 2021 spawning event is within the temporal range documented by Schaffter (1997) in 1992, when 32 white sturgeon eggs were collected from the Colusa Reach between 24 March and 21 April. Water temperatures during the 1992 survey ranged from 12° C to 16° C, with the majority of the eggs (23 of 32; 72 percent) collected on 17 April at a water temperature of 16° C. White sturgeon spawning usually occurs on a receding hydrograph Schaffter (1997). The white sturgeon egg was collected from the COL-1 site at a flow of 4,900 cfs after a peak flow of 7,500 cfs on 16 March. The majority of the sturgeon eggs collected in 1992 occurred at a flow of 6,400 cfs approximately 30 days after a peak flow of around 33,000 cfs. The 2021 Sacramento River sturgeon spawning survey was the fifth consecutive year that CDFW staff conducted sturgeon spawning surveys in the Knights Landing Reach of Sacramento River without documentation of white sturgeon spawning. While Kohlhurst (1976) collected 14 white sturgeon larvae in

the vicinity Verona in 1973 utilizing a D-net deployed near the river bottom, it is possible that spawning occurred upstream from the Verona and Knights Landing reaches. White sturgeon larvae are known to drift considerable distances prior to exogeneous feeding (Conte et al. 1988, Kynard and Parker 2005). Another possible explanation is that if spawning did occur in the Knights Landing Reach, which consists of predominantly sand and fine substrates, the sticky membrane of the eggs becomes covered with sand and sediment soon after oviposition and the eggs do not adhere to the artificial substrate of the egg mats. An insufficient number of egg mats may have also contributed to the lack of success of egg collection. Nearly one-half of the egg mats that were deployed at the beginning of the survey were lost over the duration of sampling due to vandalism or burial by mobile bedload. While white sturgeon spawning may still occur in the Knights Landing reach of the Sacramento River, it is likely that recruitment to the juvenile life stage is relatively poor, especially in low water years. The predominance of sand and fine sediment substrate does not provide interstitial spaces for oviposited eggs to collect and likely results in higher predation rates of eggs and developing larvae than in habitat consisting of large substrate. In high flow years, nearshore revetment may provide some interstitial spaces which could result in better recruitment.

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 population continues to decrease (Blackburn 2018), a number of conservation measures need to be considered. Spawning habitat enhancement through the addition of large substrates such as cobble and boulder would increase survival off eggs and developing larvae by providing more suitable intestinal spaces which in turn should decrease predation. The addition of large substrate such as cobble and boulder to known or potential sturgeon spawning habitat has been shown to be effective for lake sturgeon (*Acipenser fulvescens*) in the Detroit River. Egg mat monitoring 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). While there is some cobble and gravel sand in the Colusa Reach, spawning habitat could be enhanced by the addition of small boulders and additional cobbles. Although the Knights Landing Reach has suitable hydraulics for sturgeon spawning, the substrate consists primarily of sand and fine sediment. The addition of cobble and small boulder in suitable areas could result in increased spawning habitat and greater recruitment of white sturgeon to the late larval and early juvenile life stages.

Seasonal closures of recreational fishing in known white sturgeon spawning reaches of the Sacramento River system should also be considered as a measure to optimize spawning success. 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.

## References


Blackburn, S. E., M. L. Gingras, J. DuBois, Z. J. Jackson, and M. C. Quist. 2018. Population Demographics and Management of White Sturgeon in the Sacramento-San Joaquin River System, California. PowerPoint presentation, CDFW Work Group Meeting, 16 January 2018.

Caroffino D. C., T. M. Sutton, R. F. Elliott, and M. C. Donofrio. 2010. Early life stage mortality rates of lake sturgeon in the Peshtigo river, Wisconsin. N Am J Fish Management 30:295–304.

Colombo, R. E., J. E. Garvey, and P.S. Wills. 2007. A guide to the embryonic development of the shovelnose sturgeon (*Scaphirhynchus platorynchus*) reared at a constant temperature. Journal of Applied Ichthyology 23(4), 402-410.

Conte, F.S., S.I. Doroshov, P.B. Lutes, and E.M. Strange. 1988. Hatchery manual for the white sturgeon Acipenser transmontanus with application to other North American Acipenseridae. Cooperative Extension, University of California, Division of Agriculture and Natural Resources, Publication 3322. Davis, California.

Deng X., Van Eenennaam J.P., Doroshov S. I. 2002. Comparison of early life stages and growth of Green and White Sturgeon. In: Van Winkle W et al., editors. 2002. Biology, management, and protection of North American sturgeon. American Fisheries Society, Symposium 28, Bethesda, Maryland. p. 237-248.

Dumont, P., J. D'Amours, S. Thibodeau, N. Dubuc, R. Verdon, S. Garceau, P. Bilodeau, Y. Mailhot, and R. Fortin. 2011. Effects of the development of a newly

created spawning ground in the Des Prairies River (Quebec, Canada) on the reproductive success of Lake Sturgeon (*Acipenser fulvescens*). Journal of Applied Ichthyology
27:394–404

Fisher, J. L., J. J. Pritt, E. F. Roseman, C. G. Prichard, J. M. Craig, G. W. Kennedy, and B. A. Manny.2018. Lake Sturgeon, Lake Whitefish, and Walleye Egg Deposition Patterns with Response to Fish Spawning Substrate Restoration in the St. Clair–Detroit River System Transactions of the American Fisheries Society 147:79–93, 2018

Klimley, A. P., E. D. Chapman, J. J. Cech, D. E. Cocherell, N. A. Fangue, M. Gingras, Z. Jackson, E. A. Miller, E. A. Mora, J. B. Polleto. 2015. Sturgeon in the Sacramento-San Joaquin watershed: new insights to support conservation and management. San Francisco Estuary and Watershed Science 13(4).

Kohlhorst, D. W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. California Fish and Game, 62(1): 82-40.

Kynard, B. and E. Parker. 2005. Ontogenetic behavior and dispersal of Sacramento River white sturgeon, Acipenser transmontanus, with a note on body color. Environmental Biology of Fishes 74: 19-30.

McCabe, G.T., Jr., and Tracy, C.A., 1994. Spawning and early life history of white sturgeon, *Acipenser transmontanus*, in the lower Columbia River: U.S. Department of Commerce, NOAA NMFS Scientific Publication Office, Fishery Bulletin v. 92, no. 4, p. 760-772.

Parsley, M. J. and Beckman, L. G. 1994. White Sturgeon Spawning and Rearing Habitat in the Lower Columbia River. North American Journal of Fisheries Volume 14, Issue 4. Pages 812–827.

Poytress, W. R., J. J. Gruber, J. P. Van Eenennaam, and M. Gard. 2015. Spatial and Temporal Distribution of Spawning Events and Habitat Characteristics of Sacramento River Green Sturgeon. Transactions of the American Fisheries Society 144(6):1129-1142.

Schaffter, R. G. 1997. White sturgeon spawning migrations and locations of spawning habitats in the Sacramento River, California. California Fish and Game: 83: 1-20.

Wang Y. L., Binkowski F. P., Doroshov S. I. 1985. Effect of temperature on early development of White and Lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Environ Biol Fishes 14:43-50.