

Tagging and Monitoring of Juvenile Sturgeon in the Lower Sacramento River and Sacramento-San Joaquin Delta: 2023 Report of Findings

Purpose

The purpose of this study is to document juvenile sDPS green sturgeon (*Acipenser medirostris*) sturgeon and juvenile white sturgeon (*Acipenser transmontanus*) movements and emigration patterns in the lower Sacramento River and the SFBDE and timing of ocean entry. This study is being conducted by California Department of Fish and Wildlife (CDFW). We are proposing to capture and tag 100 juvenile green sturgeon and 100 juvenile white sturgeon per year with acoustic transmitters and monitor their spatial and temporal movement patterns with an existing array of 69 kHz transmitters deployed throughout the lower Sacramento River and SFBDE. Better understanding of movement patterns will serve to inform management, restoration, and conservation efforts for both sturgeon species. Catch per unit effort (CPUE) also serves to provide a general idea of the previous year's cohorts recruitment to the juvenile life stage for both species.

Background

The southern Distinct Population Segment (sDPS) green sturgeon is one of two sympatric sturgeon species found in river systems of California's Central Valley. The sDPS green sturgeon was listed as threatened on 16 April 2006 by the National Marine Fisheries Service (NMFS 2006). One of the principle criteria for the listing status was the general lack of information available at the time of the status review (NMFS 2006). Since ESA listing there have been several advancements in understanding the biology of green sturgeon. However, research has largely been directed at understanding the migration patterns and population dynamics of adult green sturgeon within the Sacramento River. There have been very few studies targeting the spatial and temporal components of juvenile sturgeon presence in the lower Sacramento River and SFBDE. Until the first few years of this long term study, there is little information on size, age, or potential environmental cues contributing to juvenile sturgeon movements in the SFBDE and outmigration to the Pacific Ocean. Juvenile green sturgeon are thought to be ubiquitous throughout both the delta and bay, spending up to three years throughout the lower watershed before making an ocean entry (Moyle 2002). Telemetry detections for juvenile green sturgeon tagged with acoustic transmitters the SFBDE have shown that ocean entry is not necessarily linear, in that some individuals may range throughout the SFBDE and move back into the delta after their initial entry into the Pacific Ocean. (CDFW 2024a-g), Thomas *et. al.* 2015). Information on timing, survival, and transition rates through the SFBDE is necessary for understanding potential impacts from water

diversions, dredging operations, and other projects affecting the lower Sacramento River and SFBDE.

The white sturgeon (*Acipenser transmontanus*) population, while greatly reduced in numbers from historical levels, still supports an important recreational fishery. However, this species is currently considered a Species of Special Concern by CDFW (Musick *et.al.* 2001). Beginning 17 November 2023, CDFW revised the white sturgeon sport fishing regulations. The annual maximum number of slot limit white sturgeon that may be retained was reduced from three to one per angler, and the slot size was changed from 40 to 60 inches (102 to 152 cm) to 42 to 48 inches (107 to 122 cm). Proposed future regulations for white sturgeon include either a catch and release only fishery or a retention fishery with an annual harvest quota of not more than four percent of slot limit sized fish in combination with spatial and temporal closures to protect white sturgeon on their spawning grounds. Like the green sturgeon, there is relatively little information on the movements and behavior of juvenile white sturgeon in the SFBDE. Dubois (2010) summarized the results of a CDFW multi-year set line survey (1991 to 2002) on juvenile white sturgeon distribution. Results of this study suggest that juvenile white sturgeon are distributed throughout the SFBDE, with the highest catch per unit (CPUE) effort occurring in Grizzly Bay. Unlike green sturgeon, white sturgeon spend the majority of their life within the SFBDE. To date, only adult white sturgeon originating in the SFBDE have been detected in the Pacific nearshore marine environment or in estuaries of the Pacific Northwest. Additional research is necessary to develop a greater understanding of how white sturgeon are distributed between the lower watersheds and which habitat features are most important to sustain future production.

Fisheries researchers have always been challenged by the difficulty in capturing juvenile sturgeon. There are currently many monitoring programs targeting juvenile salmonids throughout the Central Valley. However, most have had little or no success capturing juvenile sturgeon. The gear and sampling methods typically utilized for salmonid monitoring are not effective for targeting benthic species such as juvenile sturgeon. Gill nets have been utilized for the capture of juvenile green sturgeon in the Sacramento-San Joaquin delta (Radtke 1966). The previous eight years of sampling conducted for this study have shown that gill nets are highly effective for capturing juvenile sturgeon. The success of developing a protocol to capture and monitor juvenile sturgeon is important for the implementation of a long-term monitoring program. Such a program is critical for determining population level trends and potential stressors affecting the decline of these species and for implementation of species specific management strategies.

2023 is year eight of tagging and monitoring efforts supporting this long-term study. CDFW and UC Davis Biotelemetry staff captured one Age-1+ juvenile sDPS green sturgeon over 33 sampling events during 2015. The 2016 and 2017 sampling seasons were somewhat more successful, as CDFW staff captured and tagged seven juvenile green sturgeon and 11 juvenile white sturgeon in 2016 and seven juvenile green

sturgeon in 2017. The 2018 sampling season was the second most successful to date, as CDFW staff tagged 35 juvenile green sturgeon and five juvenile white sturgeon. The 2018 CPUE for juvenile green sturgeon was over ten-fold higher than in any of the previous three years of sampling. The 2019 CPUE decreased substantially compared to the 2018 CPUE and is likely a result of a below normal water year which has been shown to decrease recruitment of white sturgeon to the juvenile life stage (Fish 2010) and CPUE data from this study provides evidence to suggest that it is likely the case for green sturgeon recruitment. The 2020 CPUE for juvenile green sturgeon was the highest to date, surpassing the 2018 CPUE; as CDFW reached its goal of tagging 100 juvenile green sturgeon for the first time. Ninety-five percent of the juvenile green sturgeon tagged in 2020 were from the 2019 brood year cohort. The 2019 water year was classified as a wet water year with corresponding high Sacramento River and delta outflows which have been shown to increase recruitment to the juvenile life stage for both sturgeon species (CDFW 2024 a-g, Fish 2010). The CPUE for 2021 decreased compared to the 2020 CPUE; this was not unexpected given that the 2020 water year was classified as a dry water year. The CPUE for 2022 was similar to the CPUE for 2021, as the 2021 water year was classified as a dry water year with apparently low recruitment of juvenile sturgeon from the 2021 brood year. Analysis of telemetry data showed that the juveniles of both sturgeon species ranged both upstream and downstream in the SFBDE after tagging, with juvenile green sturgeon exhibiting at least two distinct movement patterns, including outmigration to the Pacific Ocean, and in some instances, a return to the SFBDE after several months. Juvenile white sturgeon tended to range more widely throughout the SFBDE than juvenile green sturgeon, although none were detected at the Golden Gate receiver array.

Methods

CDFW applied for and received NMFS Section 10(A)(1)(a) Permit Number 17551 that authorized the capture and tagging of up to 100 juvenile green sturgeon annually. A Section 10(A)(1)(a) permit is not required for take of white sturgeon, as they are not a federally listed species. The permit authorizes the use of gill or trammel nets to capture juvenile green sturgeon in the Sacramento River between Tisdale and Rio Vista, the San Joaquin River in the vicinity of Santa Clara Shoal, and the SFBDE in the vicinity of Grizzly Bay at Montezuma Slough. The 2023 sampling effort involved deployment of one 300-ft long by 8-ft height by 2-inch mesh gill anchored with 18-kg (40-lb) pyramid weights affixed to the ends of the lead line to minimize drift. Site selection was determined by river or delta bathymetry, current velocity, absence of large woody or anthropogenic debris, absence of submerged aquatic vegetation, and minimal quantities of drifting aquatic vegetation. Net soak times varied from 60 minutes to 240 minutes with deployment duration being dependent on water temperature and dissolved oxygen concentration (**Table 1**).

Table 1. Temperature and dissolved oxygen parameters for gill netting juvenile green sturgeon from Kahn and Mohead (2010).

Temperature at sampling depth	Minimum DO at sampling depth	% oxygen saturation at sampling depth	Net deployment time (hours)
Up to 19°C	5 mg/l	58%	4
19° to 23°C	5 mg/l	58%	2
23° to 25°	5 mg/l	58%	1
Over 25°	5 mg/l	58%	No netting

CDFW staff conducted 39 days of sampling events in 2023 between 12 January and 7 November. Data collected during sampling events included water temperature, dissolved oxygen, water depth, net set and retrieval times, and number of each fish species captured. Sampling efforts were conducted in the main channel of the Sacramento River north of Sherman Lake at rkm 82 (30 sampling events), Grizzly Bay at the western confluence of Montezuma Slough (8 events), and the main channel of the Sacramento River at Threemile Slough (one sampling event) (**Figure 1**). The Sacramento River sites have an average depth of nine meters, and the Grizzly Bay site has an average depth of three meters. Substrate at both sites is dominated by fine sediment interspersed with peat hummocks.

Captured juvenile sturgeon were identified to species, assessed for condition, and measured prior to tagging. Juvenile sturgeon were tagged with uniquely coded 69 kHz acoustic transmitters (Innovasea®) via surgical implantation into the peritoneal cavity. The tag size used for juvenile sturgeon in 2023 was a V13, which have a typical battery life of 911 days at a ping rate interval of 90-120 seconds. Juvenile sturgeon were also tagged with passive integrated transponder (PIT) tags. Attachment A includes a detailed standard operating procedure for tagging juvenile sturgeon with acoustic transmitters. Tagged juvenile sturgeon were assigned a study number (year of capture and number, e.g., GS23-01) and released near the point of capture. Brood year assignments for juvenile green sturgeon were assigned by extrapolating the fork length of young-of-year juveniles captured during late-summer through mid-fall in the Sacramento River near Red Bluff by the U.S. Fish and Wildlife juvenile green sturgeon trawl capture and tagging project to when young-of-year individuals are first encountered at the sampling sites in the SFBDE, and from documented growth rates of juvenile northern DPS green sturgeon rearing in the Klamath River (USFWS 1995).

The Sacramento River-SFBDE 69 kHz autonomous receiver array was decommissioned by the UC Davis Biotelemetry Lab (UCDBL) at the end of 2017. CDFW staff deployed receiver arrays at the Rio Vista, Antioch, and Benicia bridges in the summer of 2018 to provide minimal broad scale detection data for tagged juvenile

sturgeon. However, 69 kHz autonomous receivers were not redeployed at sampling site, rather a portable VR100-200 receiver (Innovasea®) was deployed during only during sampling events, which were typically six hours a day twice a week, therefore, there are considerable temporal gaps in the sampling site detection data for tag code IDs listed in the summary tables. However, National Marine Fisheries Service staff did maintain an array of 69 kHz acoustic release receivers at the Golden Gate after UCDBL removed the core receiver arrays in the Sacramento River. While the primary function of the acoustic release receivers was to deploy and retrieve 417 kHz receivers used to detect juvenile salmonid acoustic tags (JSATS), they also recorded detections of 69 kHz tags and therefore provided detection data for juvenile green sturgeon tagged with 69 kHz transmitters. Site residency at the Rio Vista, Antioch, Benicia, and Golden Gate receiver arrays is defined as the temporal period between the first and last detections at each receiver array without detections at any other receiver array rather than detections over a continuous period. For example, a tag ID code detected at the Rio Vista Bridge receiver array on 4, 6, 10, and 31 October was considered to have a residency period of 27 days (the temporal period between 4 to 31 October) if the tag ID code was not detected at any other receiver array between 4 and 31 October.

Results

Water temperatures and dissolved oxygen concentrations remained within the sampling thresholds through the entire 2023 sampling season (**Figure 2**). CDFW staff captured and tagged one juvenile green sturgeon during the 2023 sampling season for a catch per unit effort (CPUE) of 0.0046 per hour of net set time, and five juvenile white sturgeon for a CPUE of 0.023 per hour of net set time. The juvenile green sturgeon was captured and tagged in the main channel of the Sacramento River north of Sherman Lake. Three juvenile white sturgeon were captured and tagged in the main channel of the Sacramento River north of Sherman Lake, and two were captured and tagged in Grizzly Bay. The juvenile green sturgeon was from the 2022 brood year cohort. Four of the five juvenile white sturgeon tagged in 2022 were from the 2019 brood year cohort, and one was from the 2020 brood year cohort. (**Table 1**). **Tables 2 through 7** and **Figures 3 and 4** present the detection summaries for juvenile sturgeon tagged during the 2023 sampling season, and **Figure 5** shows receiver locations and river kilometer of the receiver locations as measured from Golden Gate Bridge.

Other native fish species captured during sampling included Central Valley fall-run Chinook salmon (*Oncorhynchus tshawytscha*); n=1, Sacramento splittail (*Pogonichthys macrolepidotus*); n=3 and Sacramento pikeminnow (*Ptychocheilus grandis*); n=4. Non-native fish species captured during sampling included striped bass (*Morone saxatilis*); n=225, and American shad (*Alosa sapidissima*); n=13.

Table 1. Study ID, date tagged, fork length, brood year, and tag codes for juvenile sturgeon tagged during the 2023 sampling season.

Study ID	Date tagged	FL (cm)	brood year	Tag ID
GS23-01	8/24/2023	48	2022	A69-1604-10888
WS23-01	2/7/2023	60	2020	A69-1604-10887
WS23-02	6/20/2023	82	2019	A69-1602-42734
WS23-03	7/26/2023	90	2019	A69-1602-42733
WS23-04	8/24/2023	84	2019	A69-1602-42729
WS22-05	10/24/2023	82	2019	A69-1602-42730

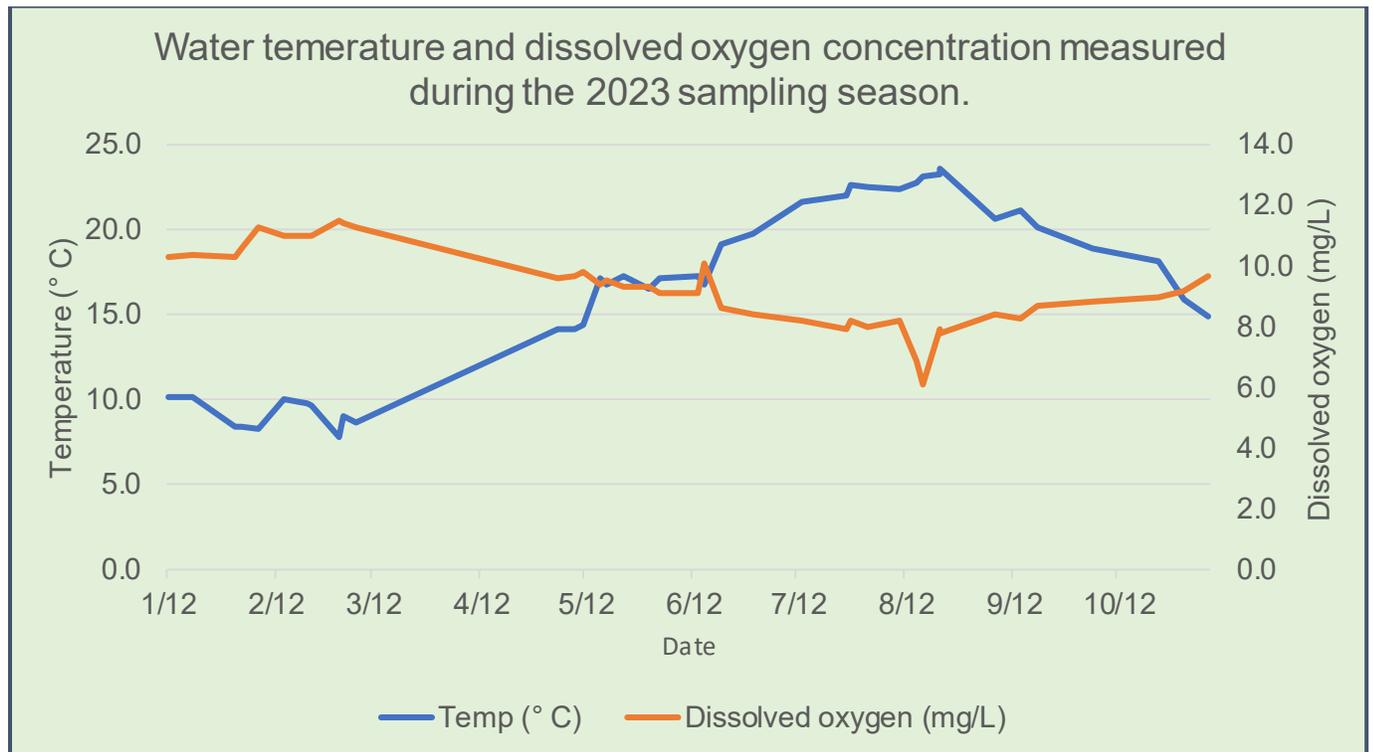


Figure 2. Water temperature and dissolved oxygen concentration measured during the 2023 sampling season.

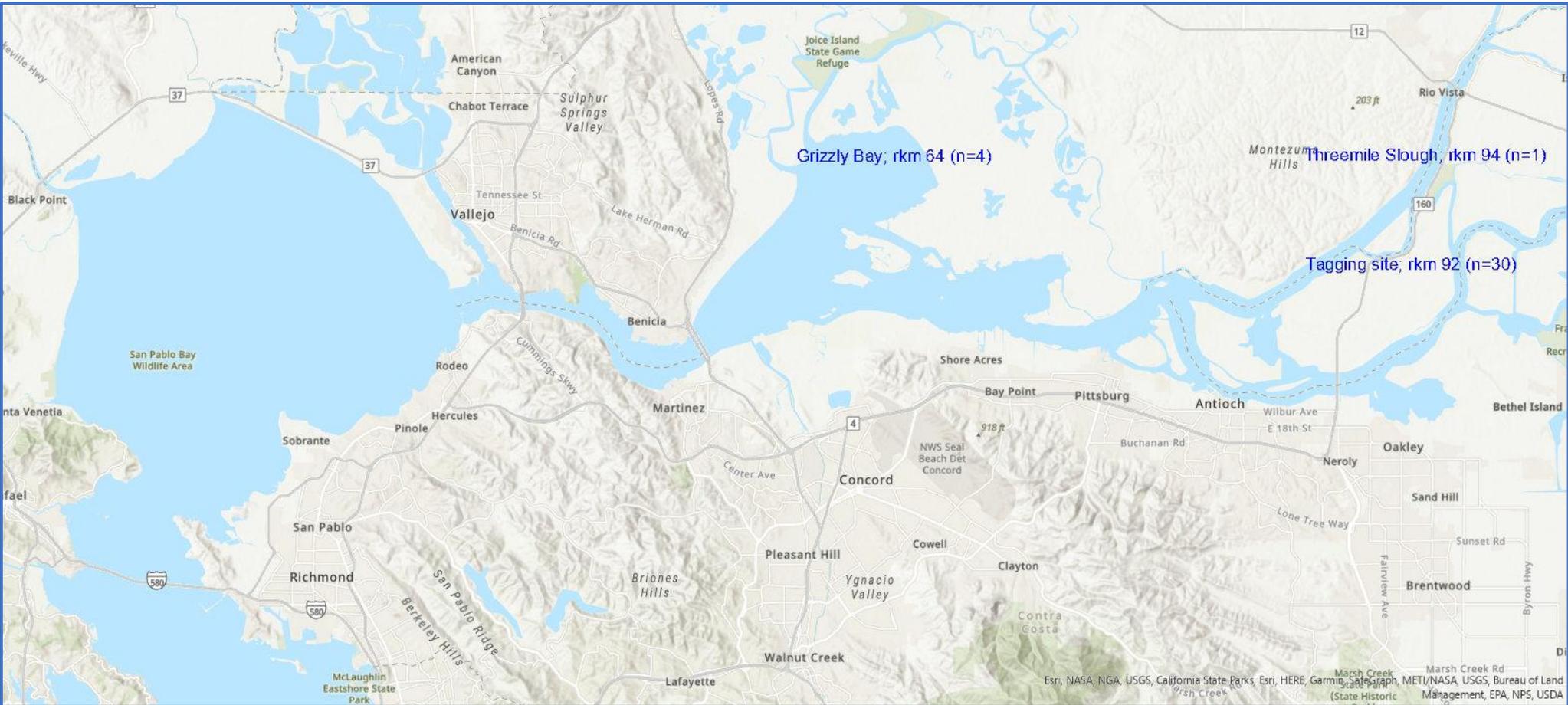


Figure 1. Juvenile sturgeon sampling locations and number of sampling events per location, 2023.

Table 2. GS23-01 Detection Summary. Brood year 2022; Tag code A69-1604-10888; tagged 24 August 2023.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
8/24/23	No detections	No detections	9/15 to 9/16/23	No detections

Tagging site residency: 1 day. Departure from the tagging site to initial detection at the Benicia Bridge: 22 days. Benicia Bridge residency: 1 day.

Table 3. WS23-01 Detection Summary. Brood year 2020; Tag code A69-1604-10887; tagged 7 February 2022.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
2/7/23 2/24/23; 10/5/23	No detections	2/22 to 2/23/23	2/10 to 2/13/23; 2/26 to 9/30/23	No detections

Initial tagging site residency: 1 day. Departure from the tagging site to initial detection at the Benicia Bridge: 6 days. Benicia Bridge residency: 3 days. Departure from the Benicia Bridge to initial detection at the Antioch Bridge: 9 days. Antioch Bridge residency: 1 day. Departure from the Antioch Bridge to next detection at the Benicia Bridge: 3 days. Second Benicia Bridge residency: 216 days. Departure from the Benicia Bridge to next detection at the tagging site: 5 days.

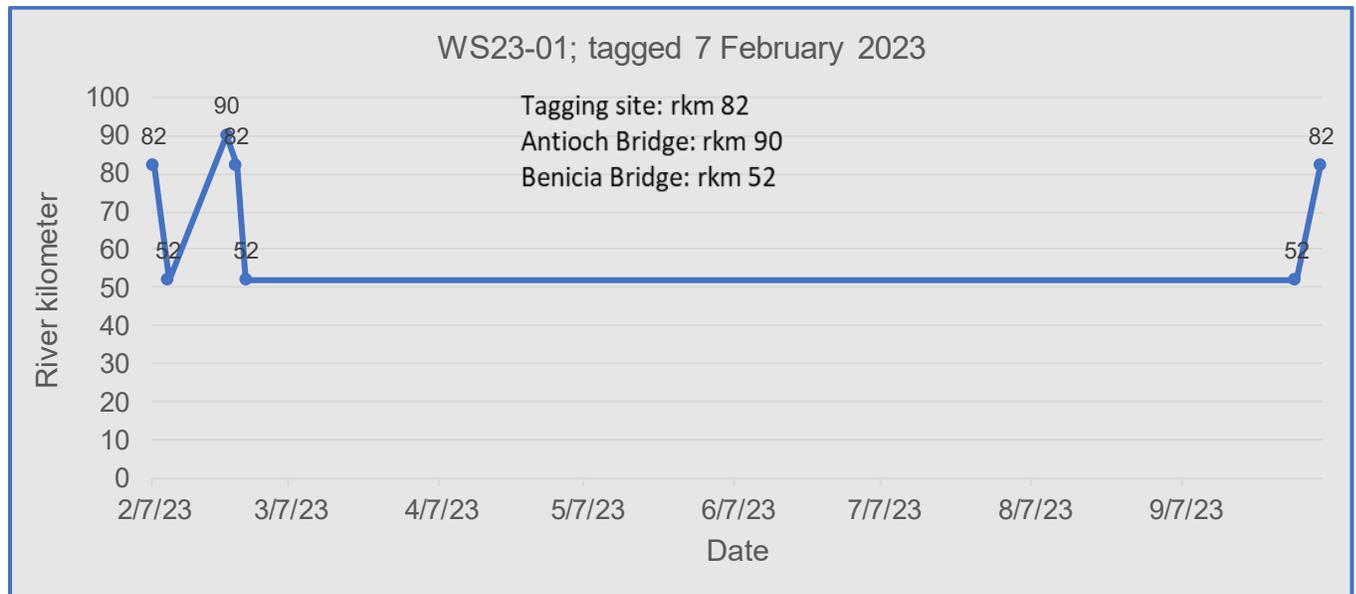


Figure 3. Detection plot for WS23-01; tagged 7 February 2023.

Table 4. WS23-02 Detection Summary. Brood year 2019; Tag code A69-1602-42734; tagged 20 June 2023.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
6/20/23; 10/31/23	No detections	9/4 to 9/9/23; 9/26 to 9/27/23	9/19 to 9/23/23; 12/29/23	No detections

Initial tagging site residency: 1 day. Departure from the tagging site to initial detection at the Antioch Bridge: 81 days. Antioch Bridge residency: 5 days. Departure from the Antioch Bridge to initial detection at the Benicia Bridge: 10 days. Initial Benicia Bridge residency: 4 days. Departure from the Benicia Bridge to next detection at the Antioch Bridge: 3 days. Second Antioch Bridge residency: 1 day. Departure from the Antioch Bridge to next detection at the tagging site: 34 days. Second tagging site residency: 1 day. Departure from the tagging site to next detection at the Benicia Bridge: 59 days. Second Benicia Bridge residency: 1 day.

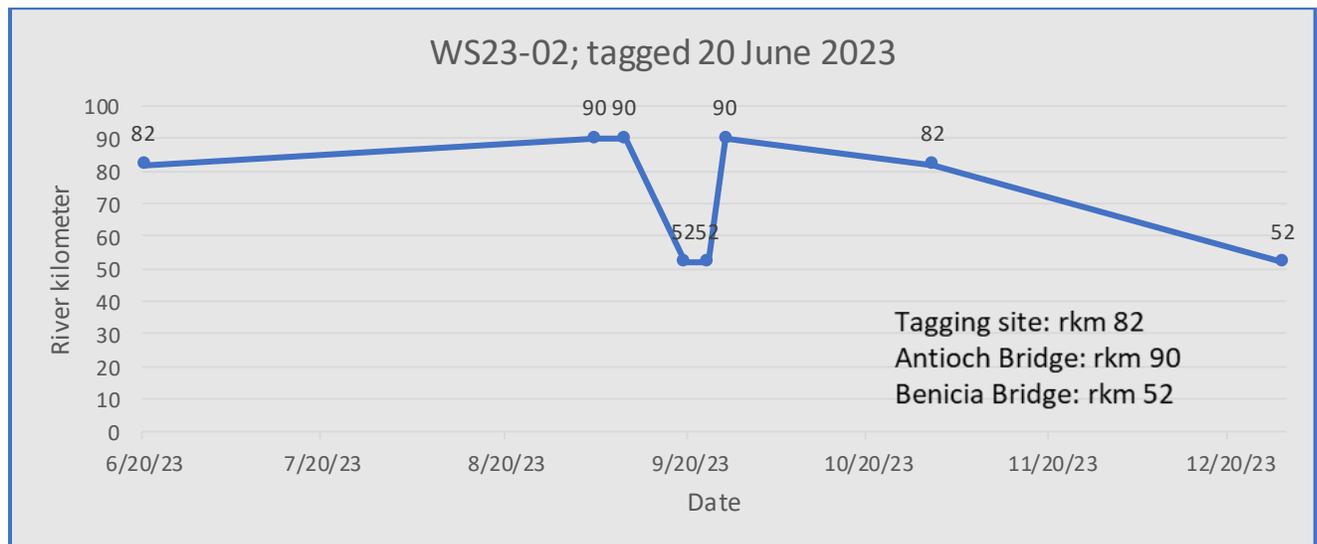


Figure 4. Detection plot for WS23-02; tagged 20 June 2023.

Table 5. WS23-03 Detection Summary. Brood year 2019; Tag code A69-1602-42733; tagged 26 July 2023.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
7/26/23	No detections	No detections	No detections	No detections

Tagging site residency: 1 day.

Table 6. WS23-04 Detection Summary. Brood year 2019; Tag code A69-1602-42729; tagged 24 August 2023.

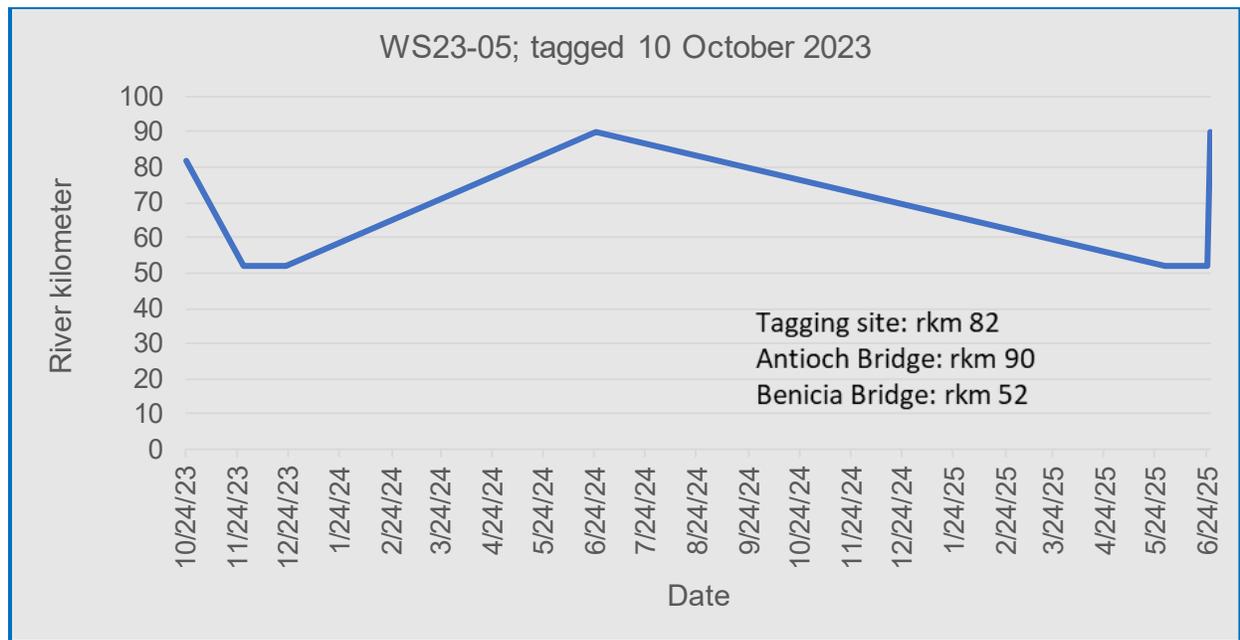
Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
8/24/23	No detections	No detections	No detections	No detections

Tagging site residency: 1 day.

Table 7. WS23-05 Detection Summary. Brood year 2019; Tag code A69-1602-42730; tagged 24 October 2023.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/24/23	No detections	6/25/24; 6/26/25	11/27 to 12/23/23; 5/30 to 6/24/2025	No detections

Initial tagging site residency: 1 day. Departure from the tagging site to initial detection at the Benicia Bridge: 34 days. First Benicia Bridge residency: 26 days. Departure from the Benicia Bridge to initial detection at the Antioch Bridge: 185 days. First Antioch Bridge residency: 1 day. Departure from the Antioch Bridge to next detection at the Benicia Bridge: 339 days. Second Benicia Bridge residency: 25 days. Departure from the Benicia Bridge to next detection at the Antioch Bridge: 2 days. Second Antioch Bridge residency: 1 day.



Green sturgeon detections and movement trends. The one juvenile green sturgeon tagged in 2023 exhibited movement patterns consistent with fish tagged in previous

years. The time of departure from the tagging site to the initial detection at the Benicia Bridge of 22 days was considerably shorter than the mean period of 135 days from tagging site departure to initial detection at the Benicia Bridge for juvenile green sturgeon tagged in previous years. To date (20 February 2024), GS23-01 has not been detected at the Golden Gate receiver array.

White sturgeon movement trends. Table 9 presents initial residency periods at the tagging site and other receiver array locations and travel times from the tagging site to initial detection at the Antioch and Benicia Bridge receiver arrays.

Table 9. Tagging site, Rio Vista Bridge, Antioch Bridge, and Benicia Bridge initial residency periods and travel times between receiver locations for juvenile white sturgeon tagged in 2019.

Residency (days)							
Tagging site (n=5)		Rio Vista (n=0)		Antioch (n=2)		Benicia (n=3)	
range	mean	range	mean	range	mean	range	mean
1	1	NA	NA	1 to 5	2.5	1 to 26	10.3
Travel time from tagging site (days)							
		Rio Vista (n=0)		Antioch (n=2)		Benicia (n=3)	
		range	mean	range	mean	range	mean
		NA	NA	81 to 185	133	6 to 96	45.3

Two juvenile white sturgeon tagged in 2023 were detected at the tagging site after their initial departure and detection at the Benicia Bridge receiver array. Both had a second residency period of one day, and both also were detected a second time at the Benicia Bridge receiver array. Second residency periods ranged from one to 126 days.

Discussion

2023 was the year nine of this study, and the 2023 CPUE for Age-1 plus juvenile green sturgeon and juvenile white sturgeon was the lowest to date and was similar to the CPUE values from the 2015 sampling season; the 2023 CPUE for juvenile white sturgeon was zero, which equaled the CPUE for Age-1 plus juvenile white sturgeon in 2017 (Table 22). The low 2023 CPUE for juvenile sturgeon is likely a result of the critically dry 2022 water year resulting in lower Sacramento River and delta outflows which decreased survival of sturgeon eggs and larvae to the juvenile life stage. The recruitment index for white sturgeon to the juvenile life stage is considerably greater in wet or above normal water years with resulting high delta outflows as compared to recruitment during dry or critically dry years with minimal delta outflows (Fish 2010). While it is not in the scope of this study to develop a recruitment index for juvenile green sturgeon, nine years of capture data generated by this study provides evidence to suggest that green sturgeon exhibit boom or bust recruitment patterns; with wet years

resulting in robust recruitment of juveniles in the following year (e.g., 2017 and 2019); while critically dry or dry years result in poor recruitment (e.g., 2014, 2015, 2021, 2022)

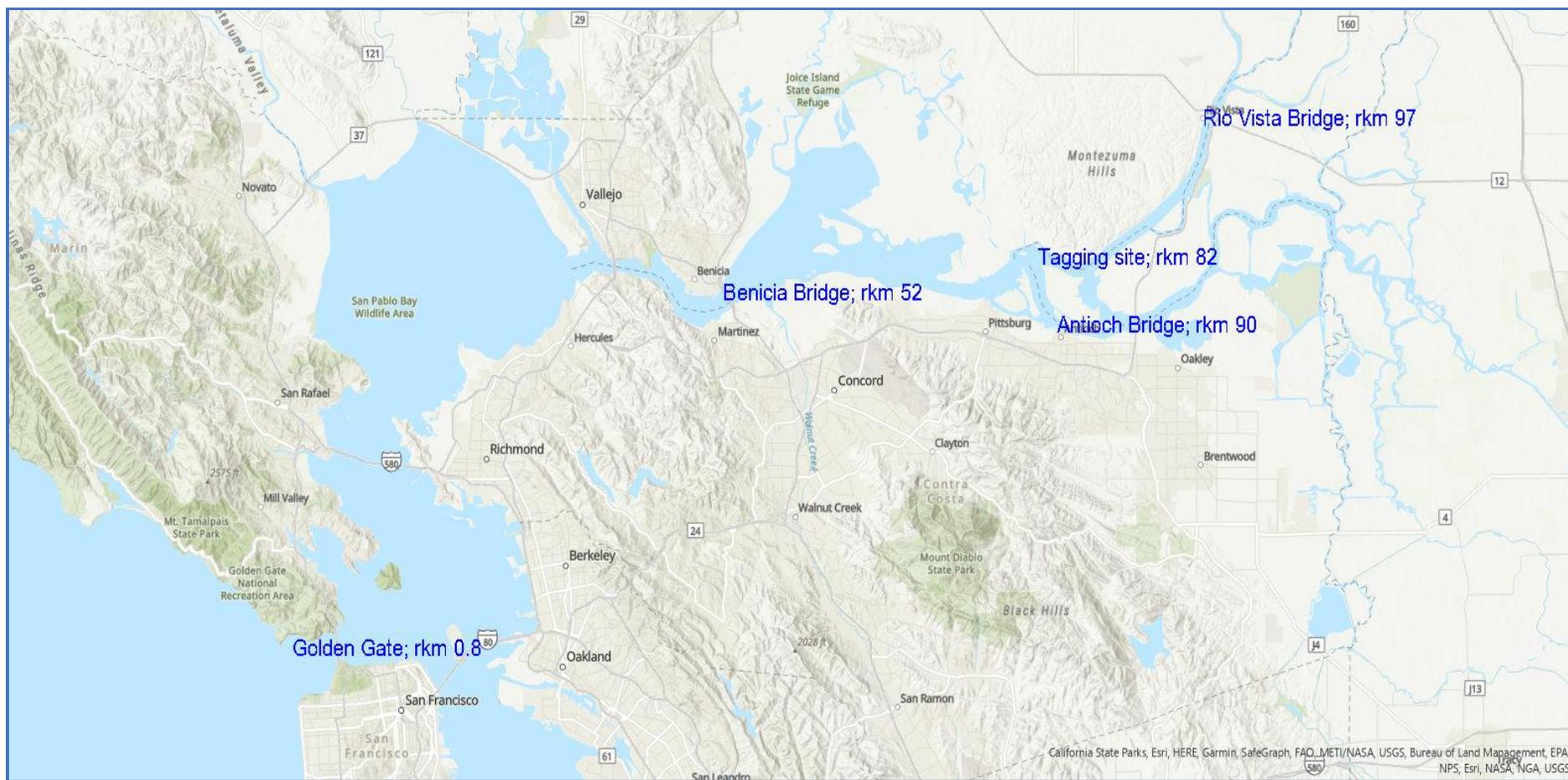


Figure 5. 2023 receiver array location map. Note that CDFW staff deployed a portable VR100-200 receiver at the sampling site only while sampling, typically six hours a day twice weekly.

Table 22. Catch per unit effort (CPUE) for 2015 through 2023; number of Age-1 plus juvenile sturgeon captured **per hour** of gill net deployment. Age-1 plus juveniles are individuals that have recruited from the previous water year (i.e., 2018 brood year fish recruited from the 2018 water year are Age-1 plus).

Sampling year	Previous water year; classification	Age-1 plus green sturgeon	CPUE	Age-1 plus white sturgeon	CPUE
2015	2014; critically dry	1	0.0033	0	0
2016	2015; critically dry	3	0.0035	10	0.012
2017	2016; dry	4	0.0083	0	0
2018	2017; wet	28	0.115	3	0.012
2019	2018; below normal	8	0.030	3	0.011
2020	2019; wet	100	0.21	20	0.018
2021	2020; dry	9	0.029	0 ¹	0
2022	2021; critically dry	11	0.0038	2	0.0070
2023	2022; critically dry	1	0.0046	5 ²	0

¹ All seven juvenile white sturgeon captured in 2021 were from the 2018 and 2019 brood year cohorts. ² All five juvenile white sturgeon captured in 2023 were from either the 2019 or 2020 brood year cohorts.

The low CPUE for both sturgeon species in 2023 and subsequent analysis of the telemetry detection data provides minimal insight on movement patterns in the SFBDE, and to date, no data regarding ocean entry of juvenile green sturgeon. 2023 was only the second year of the study in which more juvenile white sturgeon were captured than juvenile green sturgeon. U.S. Fish and Wildlife Service Red Bluff staff conduct a juvenile green sturgeon capture and tagging study in the Sacramento River in the vicinity of Red Bluff from late summer through late fall. 2022 was the first year that no juvenile green sturgeon were captured, which suggests poor recruitment to the juvenile life stage (personal communication with J. Gruber, US Fish and Wildlife Service Red Bluff).

It appears likely that the two sturgeon species may utilize different rearing habitats. White sturgeon are thought to be much more abundant than green sturgeon, although we captured and tagged nearly five-fold more juvenile green sturgeon than juvenile white sturgeon in 2019 across all brood years encountered. To date, no juvenile white sturgeon tagged in over the duration of this study have been detected at the Golden Gate receiver array. Although white sturgeon are anadromous, the vast majority of individuals spend their entire lives in the SFBDE. Juvenile white sturgeon are not known to occur in the Pacific Ocean, although several adult white sturgeon tagged in the SFBDE have been detected as far north as the Columbia River.

The removal of the 69 kHz extensive receiver array in the lower Sacramento River and SFBDE at the end of 2017 resulted in a much reduced capability to track juvenile sturgeon movements and migration patterns. Although CDFW staff deployed receiver arrays at Rio Vista, Antioch, and Benicia bridges in the summer of 2018, the overall receiver coverage in the lower Sacramento River and SFBDE was greatly reduced,

making it difficult to determine habitat utilization and fine scale movement patterns. Redeployment of a robust 69 kHz receiver array is critical to provide a better understanding of juvenile sturgeon utilization of the lower Sacramento River and SFBDE.

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