Tagging and Monitoring of Juvenile Sturgeon in the Lower Sacramento River and Sacramento-San Joaquin Delta: 2018 Report of Findings

Purpose

The purpose of this study is to document juvenile southern Distinct Population Segment (sDPS) green sturgeon (*Acipenser medirostris*) and juvenile white sturgeon (*Acipenser transmontanus*) movement and emigration patterns in the lower Sacramento River and Sacramento-San Joaquin Delta-San Francisco Bay (SFBDE) and timing of ocean entry. juvenile sturgeon in the lower Sacramento River and the SFBDE. This study is being conducted by the 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.

Background

The southern DPS 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 behaviors, habitat preferences, and population dynamics of adult green sturgeon within the main-stem Sacramento River. However, there have been very few studies targeting the spatial and temporal components of juvenile sturgeon presence in the lower Sacramento River and SFBDE. Prior to the initiation of this study, there was virtually no information on size, age, or potential environmental cues contributing to movements in the SFBDE and outmigration to the Pacific Ocean. Juvenile green sturgeon are considered 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). Preliminary telemetry detections for laboratory reared and tagged juvenile green sturgeon released in the SFBDE have shown that ocean entry is not necessarily linear, in that individuals may move back into the delta after having already reached the bay (CDFW 2015, 2016, 2017, Thomas *et. al.* 2015). Information on timing, survival, and transition rates through the SFBDE for both sturgeon species 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). Like the green sturgeon, there is relatively little information on the movements and behavior of juvenile white sturgeon in the SFBDE. Radtke (1966) offers the only published work on juvenile white sturgeon distribution. Results of this study suggest that juveniles are distributed within the lower Sacramento River and parts of the delta. Unlike green sturgeon, white sturgeon spend the majority of their life within the SFBDE, although some individuals enter the Pacific Ocean and migrate up or down the coast in the nearshore environment. Additional work is necessary to develop a greater understanding of how white sturgeon are distributed between the lower watersheds and which habitat features are most desirable 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. Limited past telemetric studies of juvenile green sturgeon were conducted by capturing larvae or early-stage juveniles near the spawning grounds and rearing them in captivity for up to ten months until juveniles were sufficiently large enough to receive an acoustic tag (Thomas et al. 2015). Otter trawls, set lines, trammel, and gill nets have all been shown to be effective methods for capturing juvenile pallid sturgeon in the Missouri River system (Spindler et al. 2009). Additionally, gill nets have been utilized for the capture of juvenile green sturgeon in the Sacramento-San Joaquin delta (Radtke 1966). The success of developing a protocol to capture and monitor juvenile sturgeon is important in the sense that it would provide a foundation in which a long-term monitoring program could be built upon. 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.

2018 is the fourth year 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. 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

likely entry into the Pacific Ocean. Juvenile white sturgeon tended to range more widely throughout the SFBDE than juvenile green sturgeon.

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 2018 sampling effort involved deployment of one 300-ft long by 8-ft height by 2-inch mesh gill net 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 bathometry, 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 34 days of sampling events in 2018 between 4 January and 28 December, although no sampling was conducted between 5 January and 16 July due to other project priorities. Data collected during sampling events included water temperature, dissolved oxygen, water depth, net set and retrieval times, and number of each fish species captured. All sampling efforts were conducted in the main channel of the Sacramento River north of Sherman Lake (rkm 82) at an average depth of 9 m, as this site had the highest CPUE for juvenile green sturgeon 2017 (**Figure 1**). Substrate in

this area is dominated by fine sediment interspersed with peat hummocks. This site also typically has considerably less drifting aquatic vegetation than upstream sampling sites. Heavy loading of drifting aquatic vegetation in the gill nets decreases capture efficacy and under periods of large tidal swings with associated strong currents causes the gill net to drift which can result in it snagging on large woody or anthropogenic debris.

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 2018 was either a V9 or V13 tag, which have typical battery lives of 274 days and 911 days respectively, at ping rate intervals of 90-120 seconds. 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.*, GS18-01) 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 Bridge on 7 June 2018 and on 12 October 2018 at the Antioch and Benicia bridges; which should provide detection data to elucidate at least broad scale movement patterns for juvenile sturgeon. However, 69 kHz autonomous receivers were not redeployed at the sampling site, which would provide continuous detection; rather a portable VR100-200 receiver (Innovasea®) was deployed during sampling events, which were typically six hours a day twice a week. Therefore, there are considerable gaps in the detection data for juvenile sturgeon at the sampling site, and to a lesser extent, for the Rio Vista, Antioch, and Benicia Bridge receiver arrays (**Figure 2**). However, National Marine Fisheries Service maintained an array of 69 kHz acoustic receivers at the Golden Gate Bridge 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 sturgeon tagged with 69 kHz transmitters. Site residency at the sampling site, 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. 69 kHz receivers deployed at Point Reyes, Point San Pedro, Ano Nuevo, and at the Cement Ship in north Monterey Bay for white shark research provided opportunistic detections for juvenile green sturgeon that entered the nearshore marine environment (**Figure 3**).

Results

Water temperatures and dissolved oxygen concentrations remained within the sampling thresholds through the entire sampling season **(Figure 4).** CDFW staff captured and tagged 35 juvenile green sturgeon during the 2018 sampling season for a (CPUE) of 0.143 per hour of net set time, and five juvenile white sturgeon for a CPUE of 0.020 per hour of net set time. All juvenile sturgeon were captured and tagged in the main channel of the Sacramento River north of Sherman Lake at a depth of approximately nine meters. The juvenile green sturgeon were from three brood year cohorts: two from brood year 2015, five from brood year 2016, and 28 from brood year 2017. The juvenile white sturgeon were also from three brood year cohorts: one from 2015, one from 2016, and three from 2017 (**Table 1**). Two juvenile green sturgeon mortalities occurred while sampling during the 2018 season, both of which were likely a result of the gill net becoming snagged on large woody debris during retrieval. Considerable force was required to dislodge the net from the snag which appeared to cause internal injuries to the sturgeon. The carcasses were vouchered for stomach content analysis. **Tables 2 through 38** and **Figures 5 through 25** present the detection summaries for juvenile green sturgeon tagged during the 2018 sampling season, and **Tables 39 through 44** and **Figures 27 through 29** present the detection summaries for juvenile white sturgeon tagged during the 2018 sampling season. Other native fish species captured during sampling included Central Valley steelhead (hatchery origin; *Oncorhynchus mykiss*) n=1, Sacramento splittail (*Pogonichthys macrolepidotus*); n=108, Sacramento pikeminnow (*Ptychocheilus grandis*); n=12, hitch (*Lavinia exilicauda*); n=22, and tule perch (*Hysterocarpus traskii*); n=12. Non-native fish species captured during sampling included striped bass (*Morone saxatilis*); n=193 and American shad (*Alosa sapidissima*); n=4.

Figure 1. Juvenile sturgeon sampling locations and number of sampling events per location, 2018.

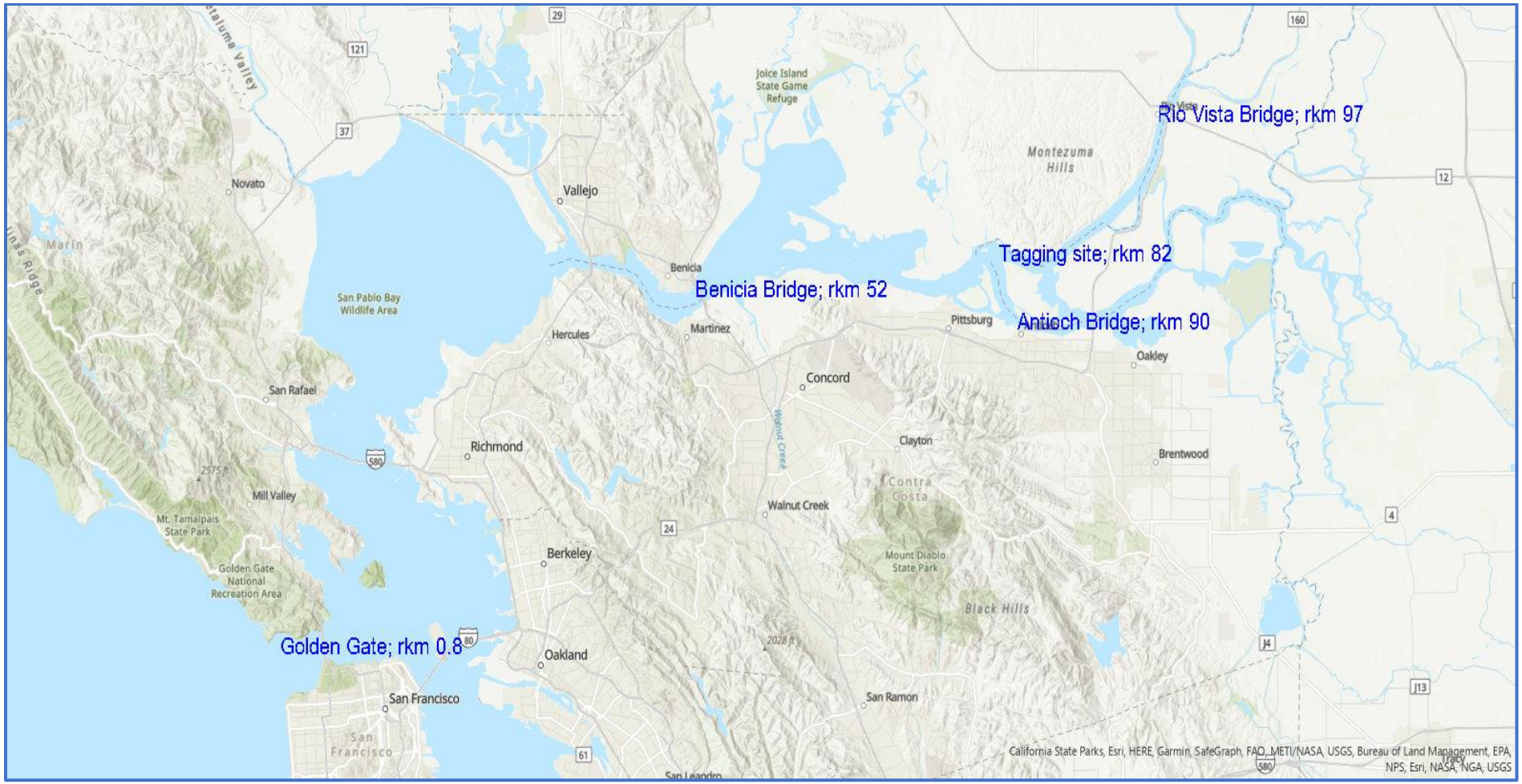

Figure 2. 2018 receiver array location map. Note that CDFW staff deployed a portable VR100-200 receiver at the sampling site only while sampling, typically six hours a day twice weekly.

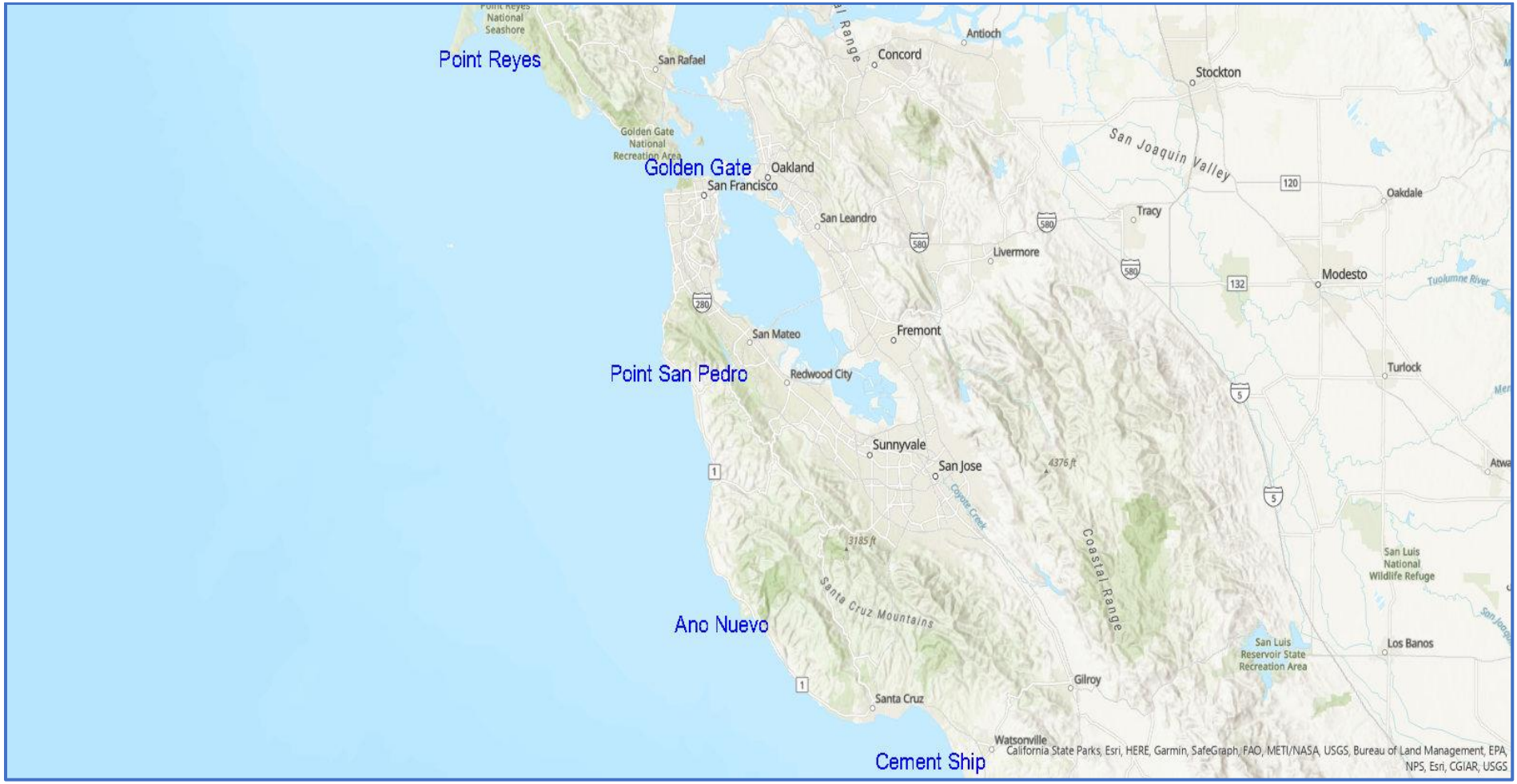

Figure 3. Pacific Ocean 69 kHz receiver array location map. Note that receivers were deployed for white shark research.

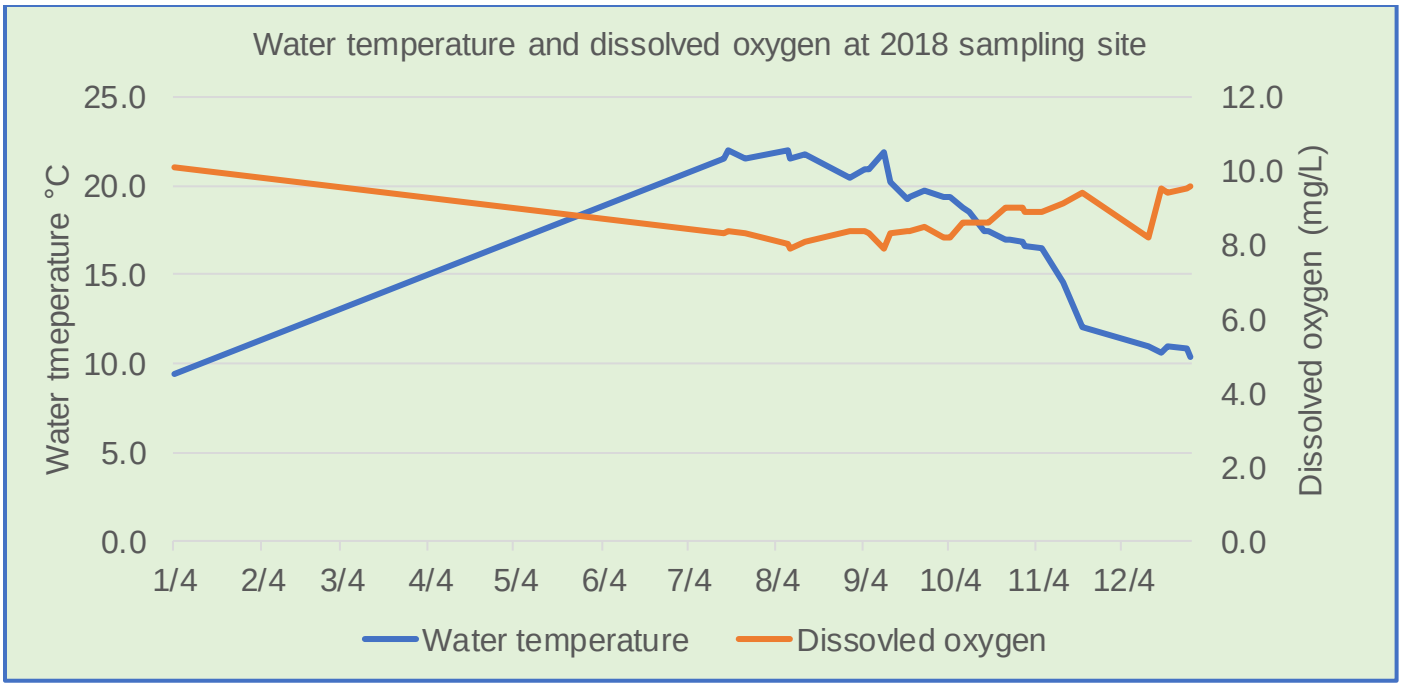

Figure 4. Water temperature and dissolved oxygen at 2018 sampling site.

Table 1. Study ID, date tagged, fork length, brood year, and tag codes for juvenile sturgeon tagged during 2018.

Study ID[1]	Date tagged	Fork length (cm)	Brood year	Tag code
GS18-01	7/24/2018	70	2015	A69-1602-1457
GS18-02	7/24/2018	46	2017	A69-1602-1458
GS18-03	7/24/2018	43	2017	A69-1602-1459
GS18-04	7/24/2018	53	2017	A69-1602-1460
GS18-05	7/24/2018	42	2017	A69-1602-1461
GS18-06	8/8/2018	50.5	2017	A69-1602-1463
GS18-07	8/9/2018	67	2016	A69-1602-1469
GS18-08	8/9/2018	43	2017	A69-1602-1464
GS18-09	8/14/2018	42	2017	A69-1602-1465
GS18-10	9/13/2018	94	2015	A69-1602-1462
GS18-11	9/19/2018	54.5	2017	A69-1601-26821
GS18-12	9/19/2018	51.5	2017	A69-1601-26819
GS18-13	9/20/2018	64	2016	A69-1601-26822
GS18-14	9/20/2018	52	2017	A69-1601-26816
GS18-15	9/25/2018	48	2017	A69-1601-26818
GS18-16	9/25/2018	53	2017	A69-1601-26817
GS18-17	9/25/2018	50	2017	A69-1601-26824
GS18-18	10/2/2018	53.5	2017	A69-1601-26823
GS18-19	10/2/2018	57.5	2017	A69-1601-32412

Study ID[1]	Date tagged	Fork length (cm)	Brood year	Tag code
GS18-20	10/2/2018	53	2017	A69-1601-32415
GS18-21	10/4/2018	53.5	2017	A69-1602-1467
GS18-22	10/4/2018	50	2017	A69-1602-1470
GS18-23	10/9/2018	54	2017	A69-1602-1466
GS18-24	10/9/2018	52	2017	A69-1602-1468
GS18-25	10/11/2018	51.5	2017	A69-1602-11438
GS18-26	10/25/2018	73.5	2016	A69-1601-26820
GS18-27	10/30/2018	39	2017	A69-1602-11445
GS18-28	10/31/2018	50	2017	A69-1602-11437
GS18-29	11/6/2018	64.5	2016	A69-1602-11452
GS18-30	12/13/2018	61	2016	A69-1602-12240
GS18-31	12/18/2018	55	2017	A69-1602-12241
GS18-32	12/18/2018	53	2017	A69-1602-12242
GS18-33	12/27/2018	61	2017	A69-1602-12231
GS18-34	12/27/2018	56	2017	A69-1602-12227
GS18-35	12/27/2018	52	2017	A69-1602-12232
WS18-01	10/2/2018	53	2017	A69-1601-32411
WS18-02	11/6/2018	81	2015	A69-1602-11444
WS18-03	11/6/2018	64	2016	A69-1602-11450
WS18-04	11/13/2018	56.5	2017	A69-1602-11436
WS18-05	11/13/2018	44	2017	A69-1602-11443

Green Sturgeon.

Table 2. GS18-01 Detection Summary. Brood year 2015; Tag code A69-1602-1457; tagged 24 July 2018.

Tagging site (rkm 92)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
7/24/18	No detections	No detections	7/27 to 7/30/2018	9/30/18 to 4/3/2019

Tagging site residency: 1 day. Tagging site departure to initial detection at the Benicia Bridge: 3 days. Benicia Bridge residency: 3 days. Benicia Bridge departure to initial detection at the Golden Gate: 60 days. Tagging site departure to initial detection at the Golden Gate: 242 days. Golden Gate residency: 185 days.

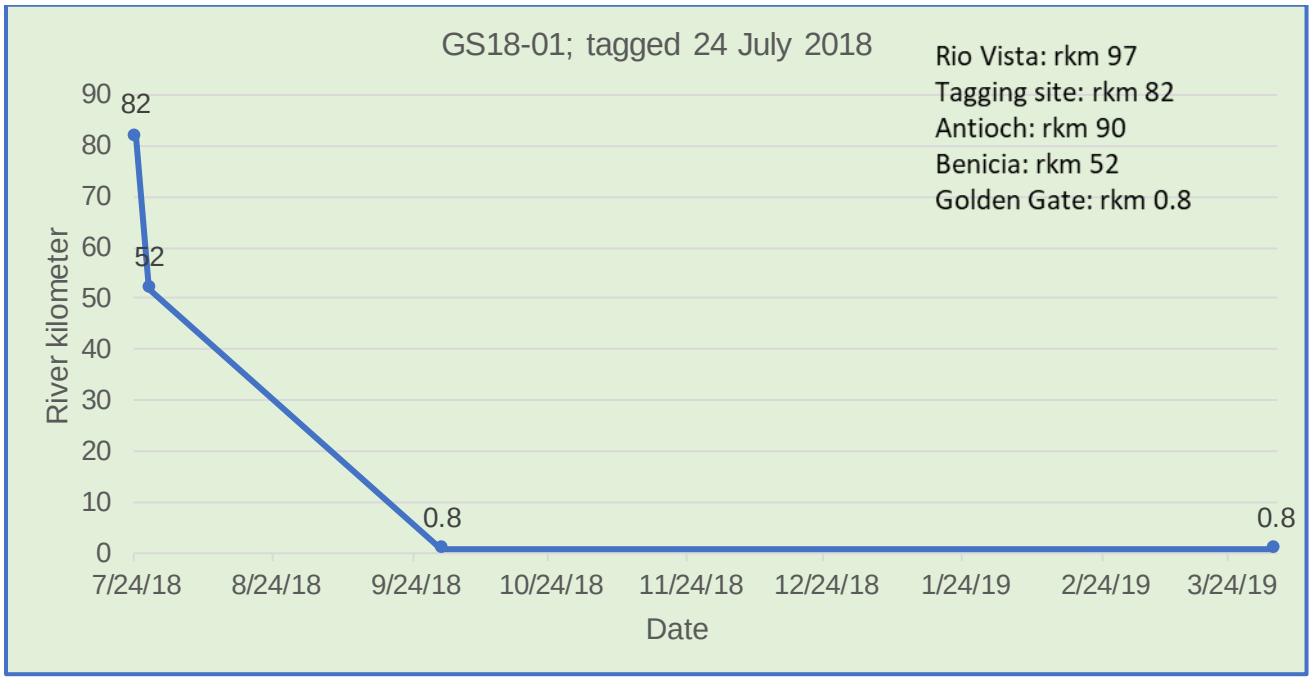

Figure 5. Detection plot for GS18-01; tagged 24 July 2018.

Table 3. GS18-02 Detection Summary. Brood year 2017; Tag code A69-1602-1458; tagged 24 July 2018.

Tagging site (rkm 92)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
7/24/18	No detections	No detections	No detections	No detections

Table 4. GS18-03 Detection Summary. Brood year 2017; Tag code A69-1602-1459; tagged 24 July 2018.

Tagging site (rkm 92)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
7/24 to 9/25/2018	No detections	No detections	10/23/18 to 1/30/2019	No detections

Tagging site residency: 63 days. Tagging site departure to initial detection at the Benicia Bridge: 92 days. Benicia Bridge residency: 37 days.

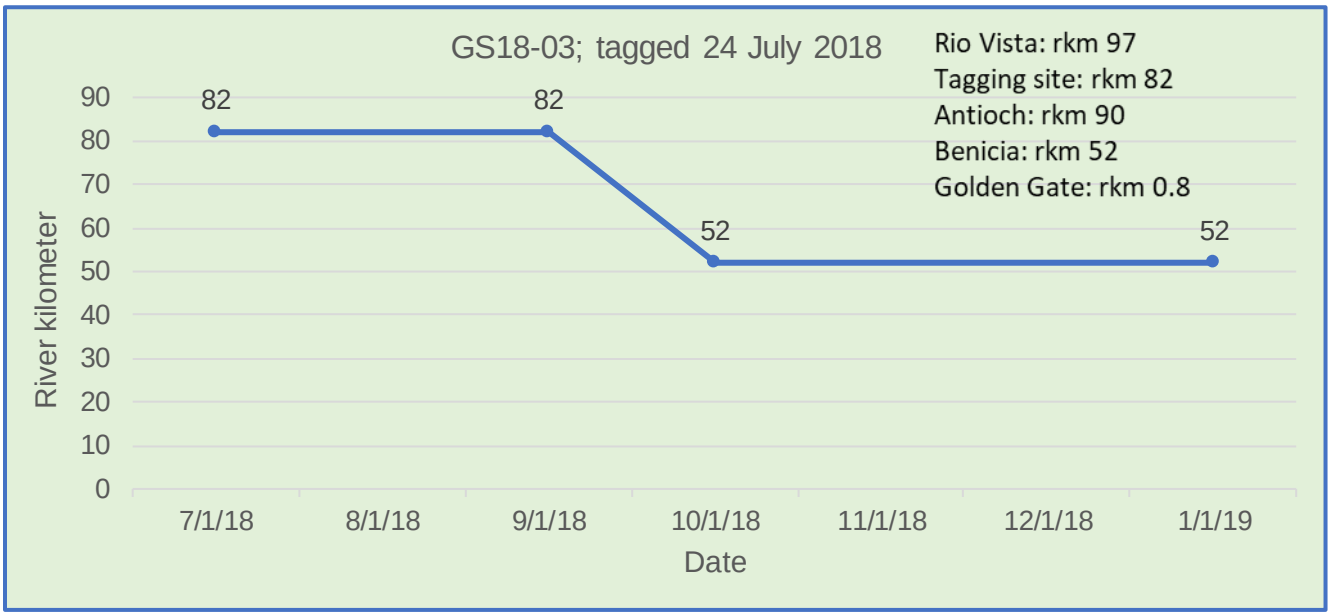

Figure 6. Detection plot for GS18-03; tagged 24 July 2018.

Table 5. GS18-04 Detection Summary. Brood year 2014; Tag code A69-1602-1460; tagged 24 July 2017.

Tagging site (rkm 86)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
7/24/18	No detections	No detections	No detections	No detections

Tagging site residency: 1 day.

Table 6. GS18-05 Detection Summary. Brood year 2017; Tag code A69-1602-1461; tagged 24 July 2017.

Tagging site (rkm 92)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
7/24 to 8/1/18	No detections	No detections	No detections	No detections

Tagging site residency: 8 days.

Table 7. GS18-06 Detection Summary. Brood year 2017; Tag code A69-1602-1463; tagged 8 August 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
8/9 to 9/25/18	No detections	No detections	10/26 to 10/28/18	No detections

Tagging site residency: 48 days.

Table 8. GS18-07 Detection Summary. Brood year 2015; Tag code A69-1602-1469; tagged 9 August 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
8/9 to 12/27/18	No detections	No detections	No detections	No detections

Tagging site residency: 140 days.

Table 9. GS18-08 Detection Summary. Brood year 2015; Tag code A69-1602-1464; tagged 9 August 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
8/9 to 12/20/18	No detections	No detections	No detections	No detections

Tagging site residency: 133 days.

Table 10. GS18-09 Detection Summary. Brood year 2017; Tag code A69-1602-1465; tagged 14 August 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
8/14 to10/4/18	No detections	No detections	11/12/18 to 7/20/19	No detections

Tagging site residency: 51 days. Tagging site departure to initial detection at the Benicia Bridge: 90 days. Benicia Bridge residency: 317 days.

Table 11. GS18-10 Detection Summary. Brood year 2015; Tag code A69-1602-1462; tagged 13 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/13/18	No detections	No detections	No detections	9/23/18 to 8/18/19

Tagging site residency: 1 day. Tagging site departure to initial detection at the Golden Gate: 10 days. Golden Gate residency: 329 days.

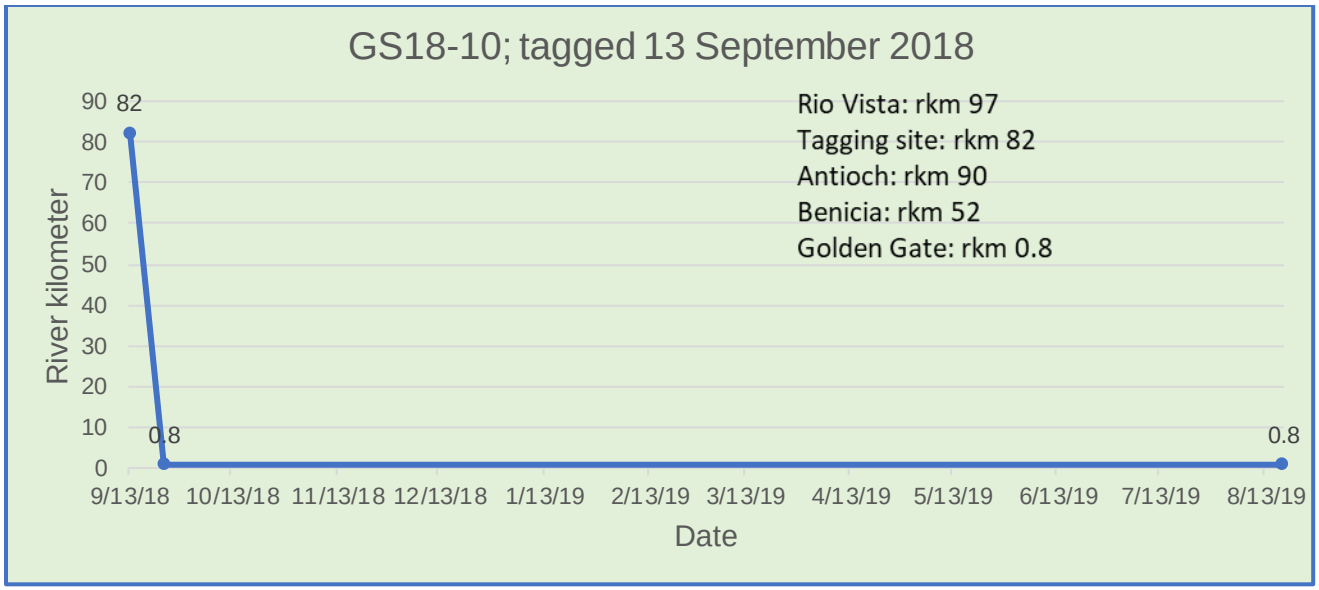

Figure 7. Detection plot for GS18-10; tagged 13 September 2018.

Table 12. GS18-11 Detection Summary. Brood year 2017; Tag code A69-1601-26821; tagged 19 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/19 to 10/25/18	No detections	No detections	11/3 to 11/7/18 8/29/19; 8/18/20	1/28 to 7/31/19; 9/12/19 to 6/9/20; 8/28 to 8/29/20; 12/16/20

Tagging site residency: 36 days. Tagging site departure to initial detection at the Benicia Bridge: 9 days. Initial Benicia Bridge residency: 4 days. Benicia Bridge departure to initial detection at the Golden Gate: 82 days. Initial Golden Gate residency: 184 days. Golden Gate departure to next detection at the Benicia Bridge: 29 days. Second Benicia Bridge residency: 1 day. Second departure from the Benicia Bridge to next detection at the Golden Gate: 14 days. Second residency period at the Golden Gate: 282 days. The second residency period also included a foray into the Pacific Ocean. GS18-11 was detected at the Golden Gate on 31 March 2020; the next detection was at Point San Pedro on 10 April 2020 which is about 28 kilometers south of the Golden Gate. GS18-11 appeared to remain in the Pacific Ocean until 9 June 2020 when it was again detected at the Golden Gate. GS18-11 was subsequently detected as far upstream as the Benicia Bridge on 18 August 2020 before returning to the Golden Gate nine days later.

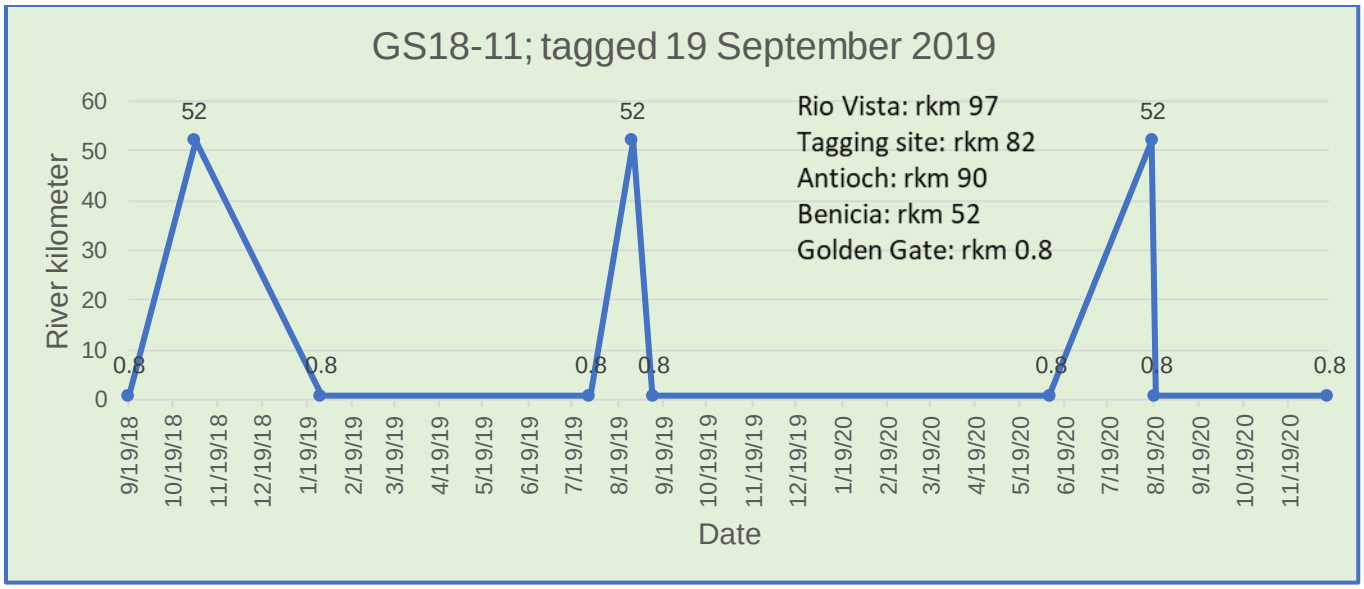

Figure 8. Detection plot for GS18-11; tagged 13 September 2018.

Table 13. GS18-12 Detection Summary. Brood year 2016; Tag code A69-1601-26819; tagged 20 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/20 to 10/11/18	7/29/19	No detections	10/21/18 to 7/23/19	12/20/19 to 2/6/20

Tagging site residency: 22 days. Tagging site departure to initial detection at the Benicia Bridge: 10 days. Benicia Bridge residency: 275 days. Departure from the Benicia Bridge to Rio Vista Bridge: 6 days: Departure from the Rio Vista Bridge to first detection at the Golden Gate: 144 days. Golden Gate residency: 48 days.

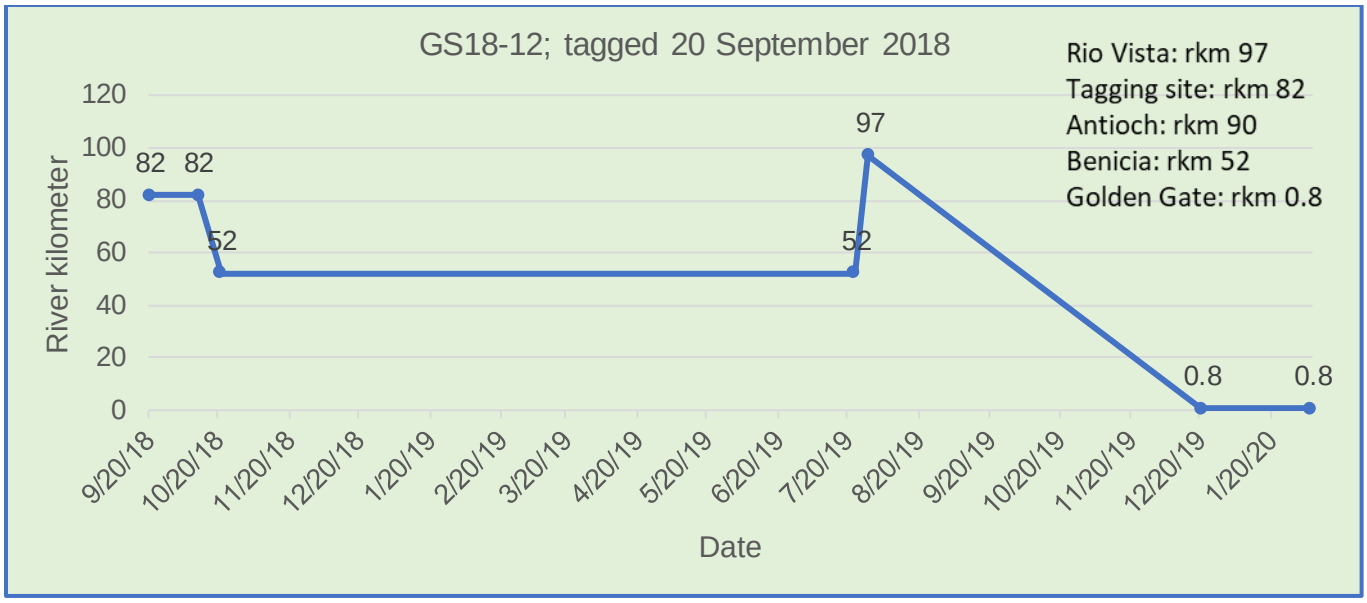

Figure 9. Detection plot for GS18-12; tagged 20 September 2018.

Table 14. GS18-13 Detection Summary. Brood year 2017; Tag code A69-1601-26822; tagged 19 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/20/18 to 10/2/18	No detections	No detections	10/11/18 to 2/18/19	2/24/19 to 2/26/20

Tagging site residency: 12 days. Tagging site departure to initial detection at the Benicia Bridge: 9 days. Benicia Bridge residency: 130 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 6 days. Golden Gate residency: 2 days.

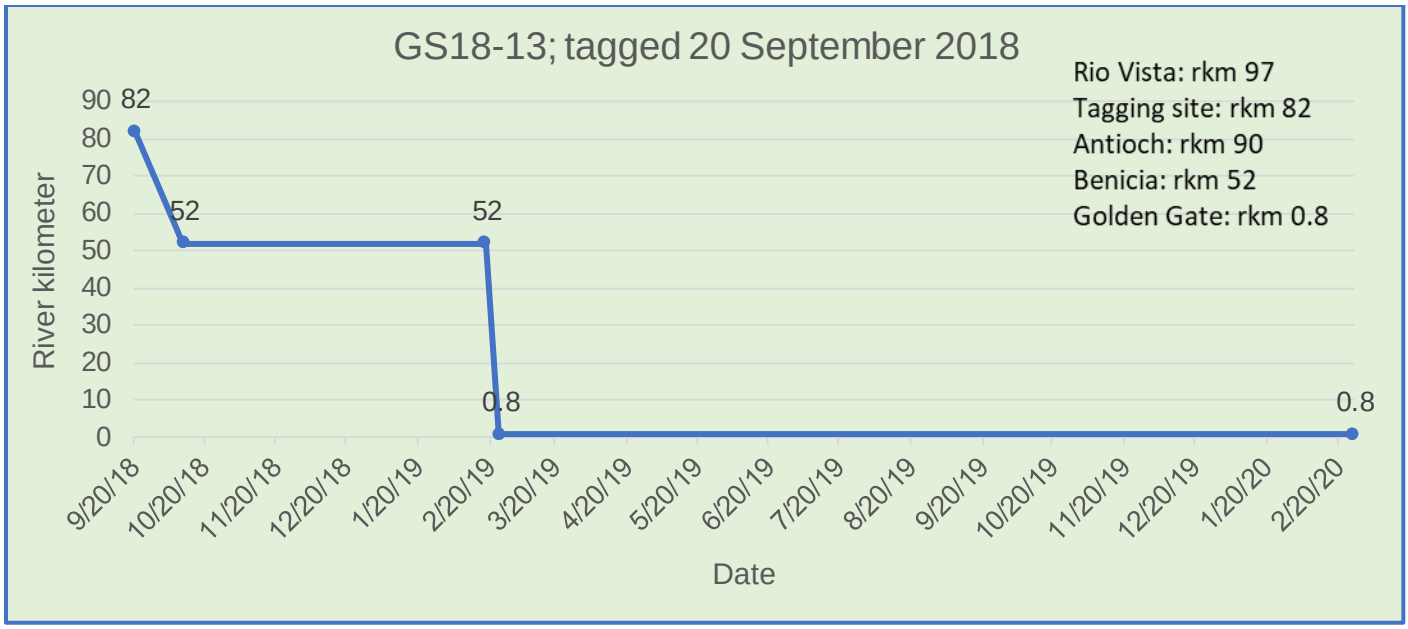

Figure 10. Detection plot for GS18-13; tagged 20 September 2018.

Table 15. GS18-14 Detection Summary. Brood year 2017; Tag code A69-1601-26816; tagged 20 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/20/18	No detections	No detections	No detections	No detections

Tagging site residency: 1 day.

Table 16. GS18-15 Detection Summary. Brood year 2017; Tag code A69-1601-26818; tagged 25 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/25/18 to 2/7/19	No detections	No detections	7/25 to 8/3/19	3/16 to 12/12/20

Tagging site residency: 135 days. Tagging site departure to initial detection at the Benicia Bridge: 168 days. Benicia Bridge residency: 9 days. Departure from the Benicia Bridge to the Golden Gate: 226 days. Golden Gate residency: 271 days.

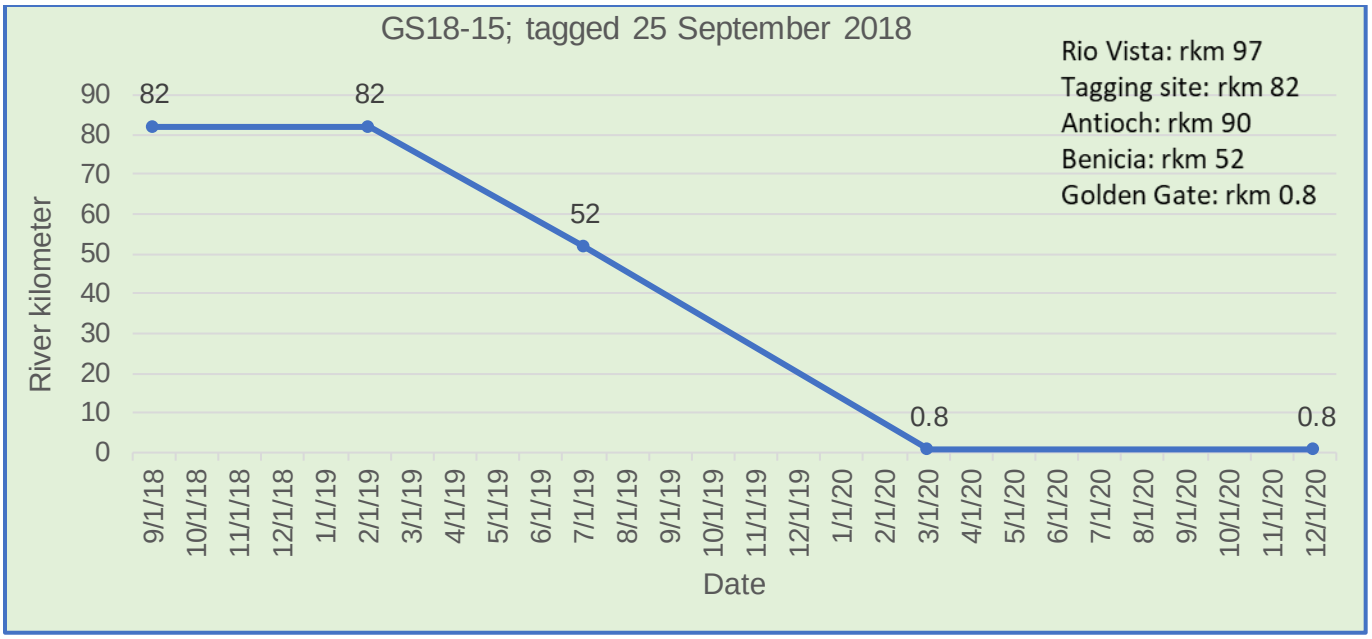

Figure 11. Detection plot for GS18-15; tagged 25 September 2018.

Table 17. GS18-16 Detection Summary. Brood year 2017; Tag code A69-1601-26817; tagged 25 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/25/18	No detections	12/1/18	10/23/18 to 3/22/19; 5/31 to 6/12/20	1/25 to 3/19/20; 7/12 to 9/21/20

Tagging site residency: 1 day. Tagging site departure to initial detection at the Benicia Bridge: 28 days. Initial Benicia Bridge residency: 150 days. Departure from the Benicia Bridge to the Golden Gate: 312 days. Initial Golden Gate residency: 54 days. The initial residency period at the Golden Gate also included a foray into the Pacific Ocean. GS18-16 was detected at the Golden Gate on 25 January 2020; the next detection was at Point San Pedro on 9 March 2020 which is about 28 kilometers south of the Golden Gate. GS18-16 appeared to remain in the Pacific Ocean until 19 March 2020 when it was again detected at the Golden Gate. GS18-11 was subsequently detected as far upstream as the Benicia Bridge between 31 May and 12 June 2020 before returning to the Golden Gate 30 days later on 12 July 2020.

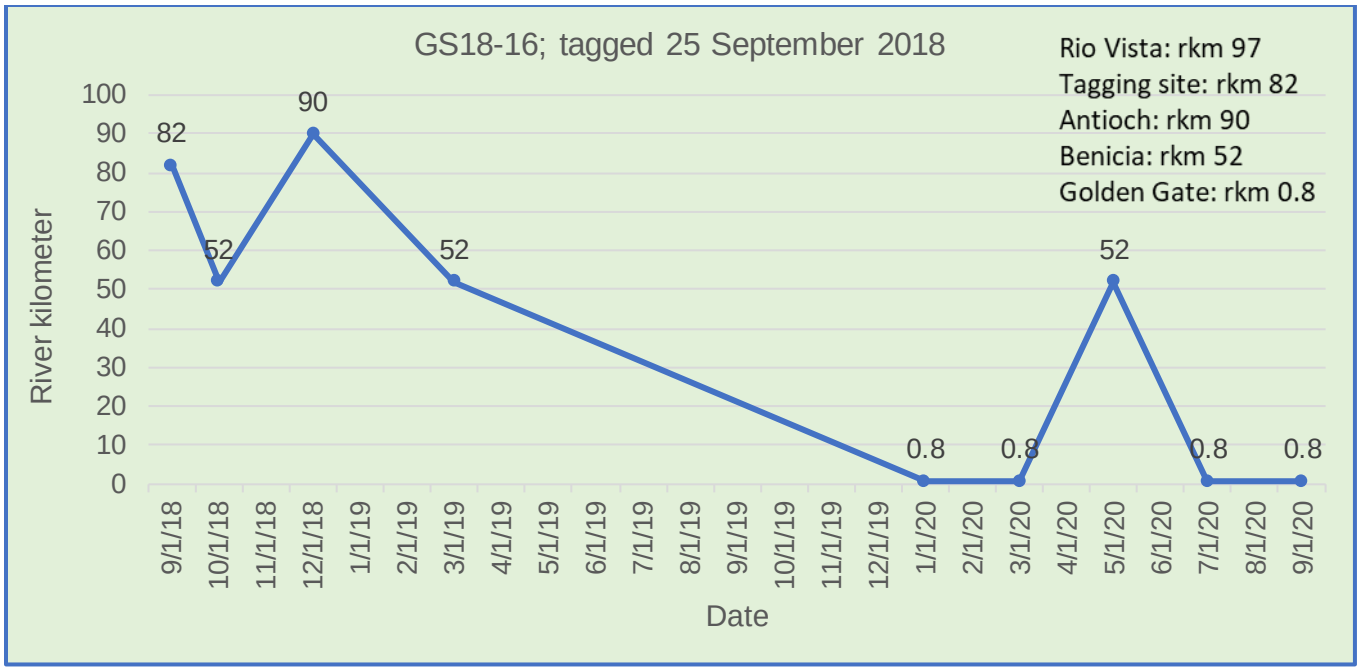

Figure 12. Detection plot for GS18-16; tagged 25 September 2018.

Table 18. GS18-17 Detection Summary. Brood year 2017; Tag code A69-1601-26824; tagged 25 September 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
9/25/18	No detections	No detections	No detections	No detections

Tagging site residency: 1 day.

Table 19. GS18-18 Detection Summary. Brood year 2017; Tag code A69-1601-26823; tagged 2 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/2/18 to 1/10/19	5/5 to 5/6/19	No detections	No detections	10/29/19 to 12/31/20

Tagging site residency: 100 days. Tagging site departure to initial detection at the Rio Vista Bridge: 115 days. Rio Vista Bridge departure to the Golden Gate: 176 days. Golden Gate residency: 429 days.

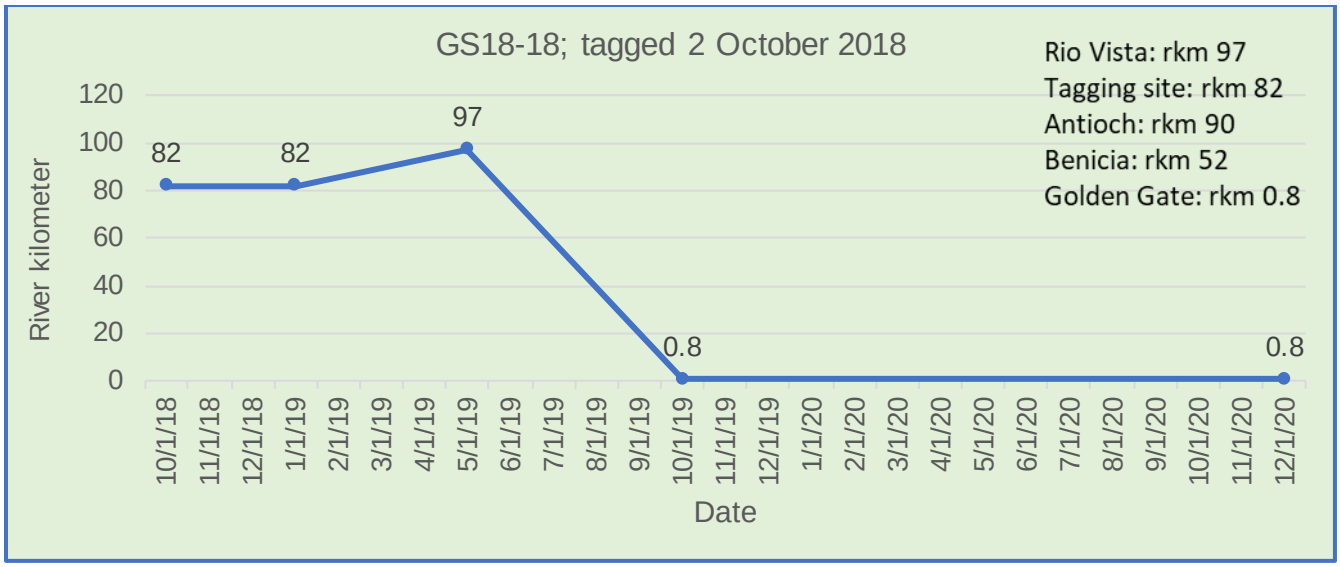

Figure 13. Detection plot for GS18-18; tagged 2 October 2018.

Table 20. GS18-19 Detection Summary. Brood year 2017; Tag code A69-1601-32412; tagged 2 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/2/18	No detections	No detections	11/10/19 to 12/11/19	1/4/20 to 3/5/21

Tagging site residency: 1 day. Tagging site departure to initial detection at the Benicia Bridge: 404 days. Benicia Bridge residency: 31 days. Departure from the Benicia Bridge to the Golden Gate: 24 days. Golden Gate residency: 426 days.

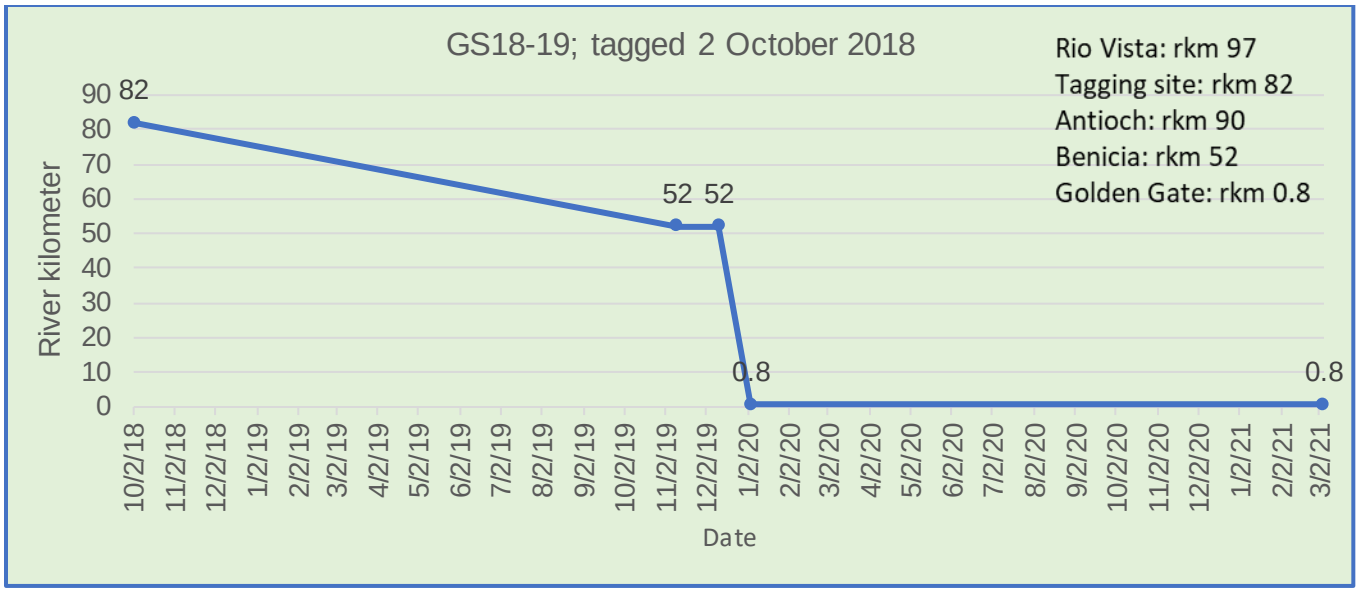

Figure 14. Detection plot for GS18-19; tagged 2 October 2018.

Table 21. GS18-20 Detection Summary. Brood year 2017; Tag code A69-1601-32415; tagged 2 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/2 to 10/18/18	No detections	No detections	1/27 to 2/16/19; 8/11 to 8/12/20	5/29/19 to 6/24/20; 9/4/20 to 1/16/21

Tagging site residency: 16 days. Tagging site departure to initial detection at the Benicia Bridge: 101 days. Initial Benicia Bridge residency: 20 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 102 days. Initial Golden Gate residency: 392 days. The initial residency period at the Golden Gate also included a foray into the Pacific Ocean. GS18-20 was detected at the Golden Gate on 23 February 2020; the next detections were at Point San Pedro on 27 to 28 February and 9 March 2020 which is about 28 kilometers south of the Golden Gate. GS18-20 appeared to remain in the Pacific Ocean until 9 March 2020 when it was again detected at the Golden Gate on 1 May 2020. GS18-11 was subsequently detected as far upstream as the Benicia Bridge 11 to 12 June 2020 before returning to the Golden Gate 23 days later on 4 September 2020.

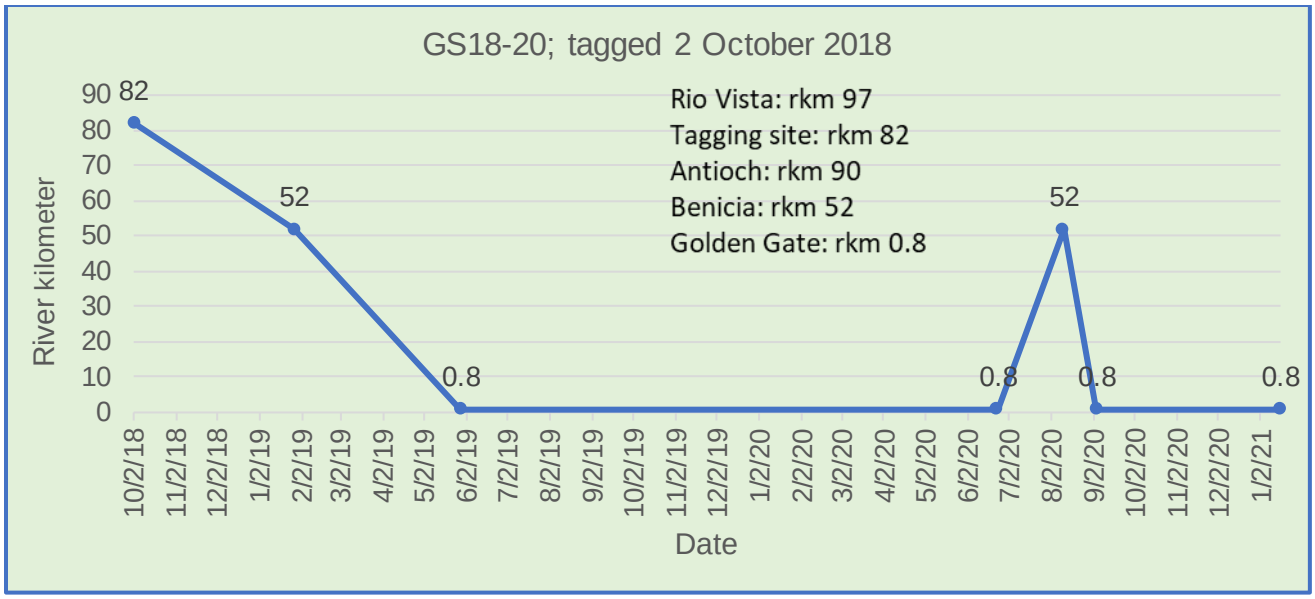

Figure 15. Detection plot for GS18-20; tagged 2 October 2018.

Table 22. GS18-21 Detection Summary. Brood year 2017; Tag code A69-1602-1467; tagged 4 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/4/18 to 2/7/19	No detections	No detections	4/3 to 6/12/19	8/26 to 8/31/19

Tagging site residency: 126 days. Tagging site departure to initial detection at the Benicia Bridge: 55 days. Benicia Bridge residency: 70 days. Departure from the Benicia Bridge to the Golden Gate: 75 days. Golden Gate residency: 5 days.

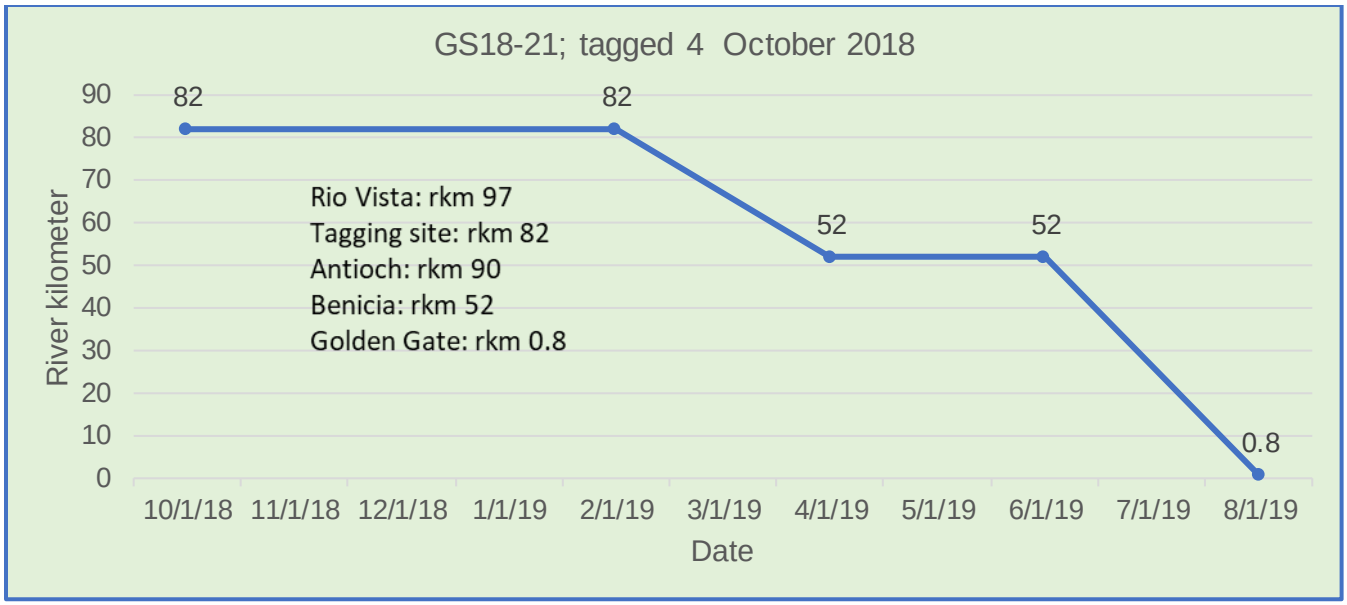

Figure 16. Detection plot for GS18-21; tagged 4 October 2018.

Table 23. GS18-22 Detection Summary. Brood year 2017; Tag code A69-1602-1470; tagged 4 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/4/18 to 2/7/19	No detections	No detections	No detections	4/14 to 4/15/19

Tagging site residency: 126 days. Departure from tagging site to initial detection at the Golden Gate: 66 days. Golden Gate residency: 1 day.

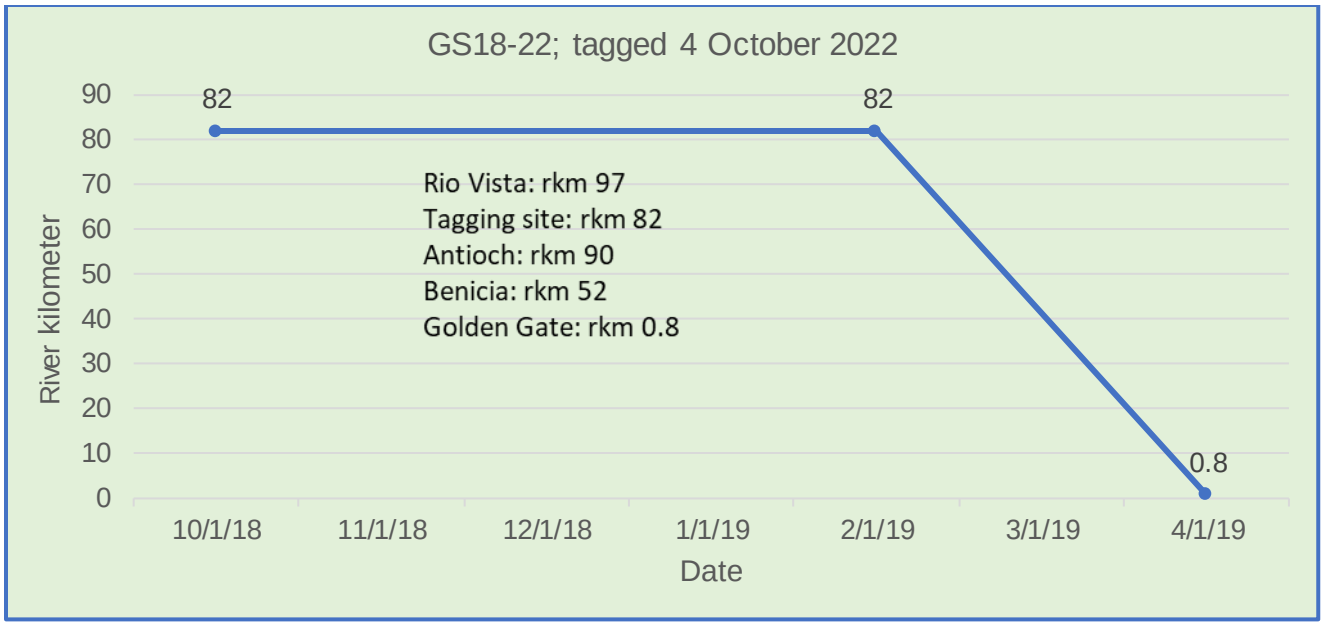

Figure 17. Detection plot for GS18-22; tagged 4 October 2018.

Table 24. GS18-23 Detection Summary. Brood year 2017; Tag code A69-1602-1466; tagged 9 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/9 to 10/25/18	No detections	No detections	11/28 to 12/6/18	12/18/18 to 7/30/19

Tagging site residency: 16 days. Departure from tagging site to initial detection at the Benicia Bridge: 34 days. Benicia Bridge residency: 8 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 12 days. Golden Gate residency: 224 days.

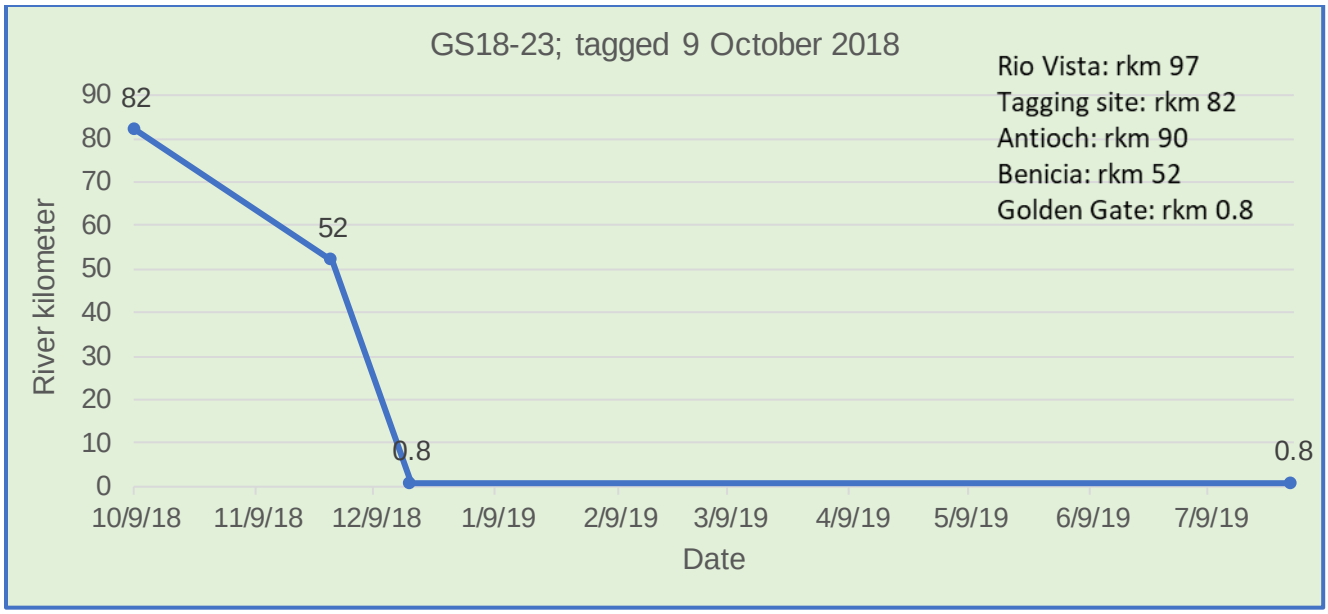

Figure 18. Detection plot for GS18-23; tagged 9 October 2018.

Table 25. GS18-24 Detection Summary. Brood year 2017; Tag code A69-1602-1468; tagged 9 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/9 to 11/13/18	No detections	No detections	No detections	1/13/19 to 9/21/19

Tagging site residency: 13 days. Departure from tagging site to initial detection at the Golden Gate: 61 days. Golden Gate residency: 251 days.

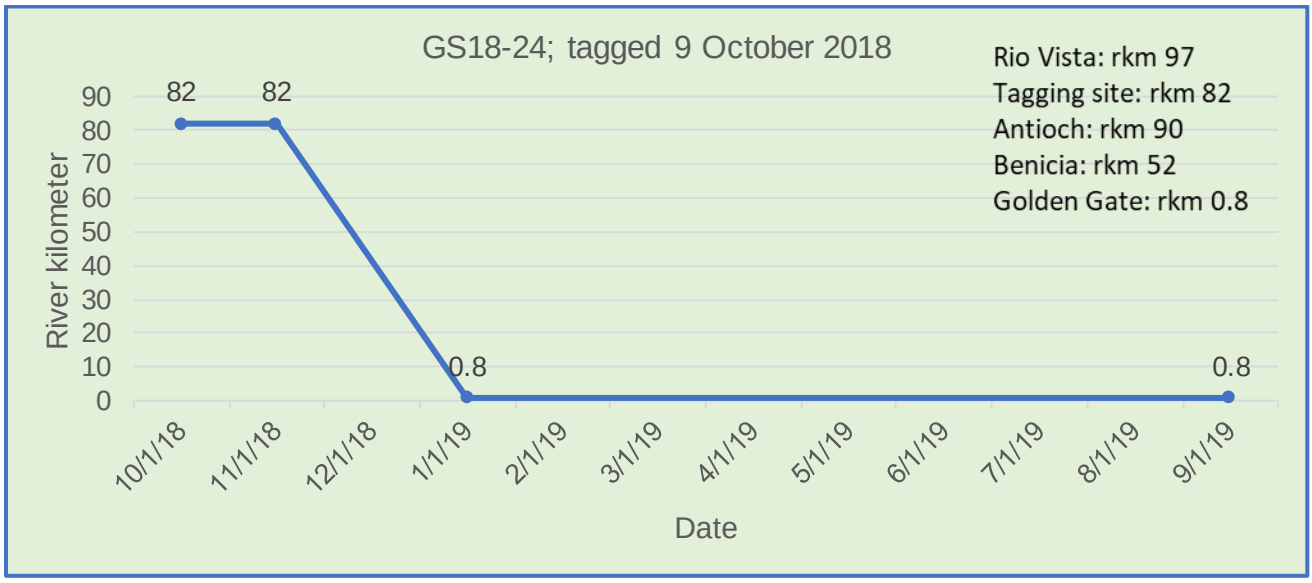

Figure 18. Detection plot for GS18-24; tagged 9 October 2018.

Table 26. GS18-25 Detection Summary. Brood year 2017; Tag code A69-1602-11438; tagged 11 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/11/18 to 10/25/18	No detections	No detections	12/21/18	2/7/19 to 9/18/19

Tagging site residency: 14 days. Departure from tagging site to initial detection at the Benicia Bridge: 57 days. Benicia Bridge residency: 1 day. Departure from the Benicia Bridge to initial detection at the Golden Gate: 251 days. Golden Gate residency: 223 days.

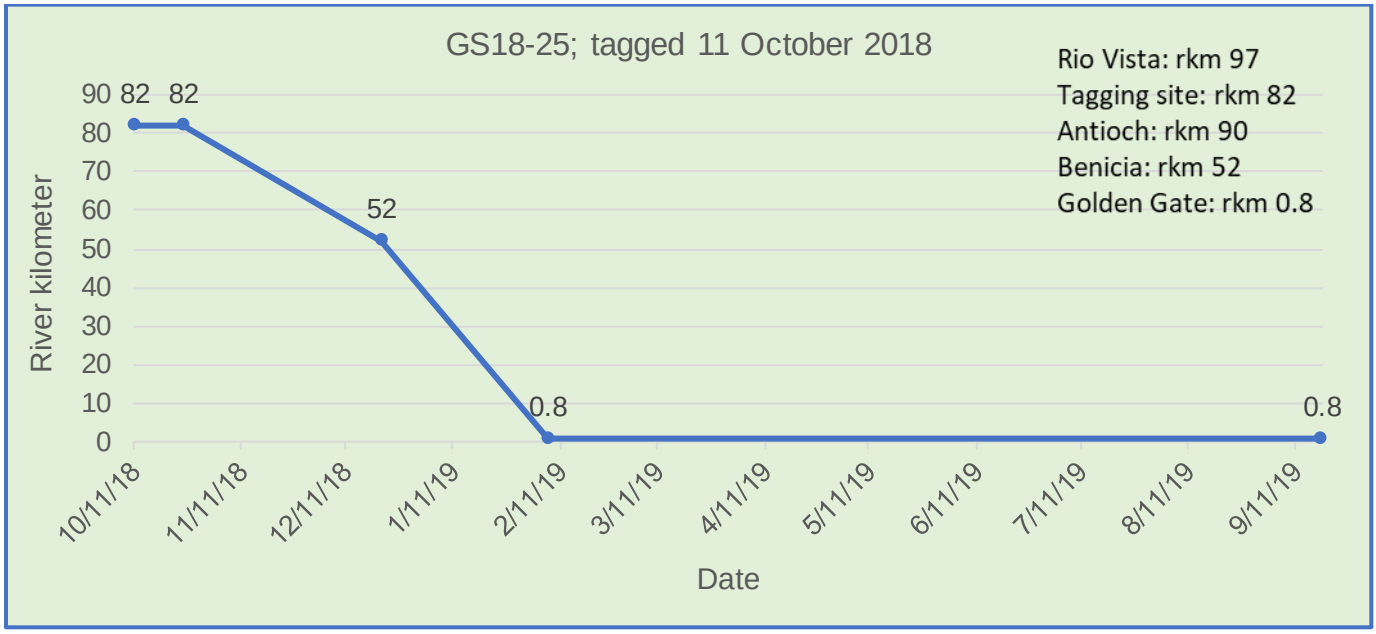

Figure 19. Detection plot for GS18-25; tagged 9 October 2018.

Table 27. GS18-26 Detection Summary. Brood year 2016; Tag code A69-1601-26820; tagged 25 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/25 to 12/27/18	No detections	No detections	1/11 to 1/12/19	2/06/19 to 9/26/20

Tagging site residency: 63 days. Departure from tagging site to initial detection at the Benicia Bridge: 15 days. Benicia Bridge residency: 2 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 25 days. Golden Gate residency: 554 days. The initial residency period at the Golden Gate also included a foray into the Pacific Ocean. GS18-26 was detected at the Golden Gate on 2 March 2020; the next detection was at Point San Pedro on 24 March 2020 which is about 28 kilometers south

of the Golden Gate. GS18-26 appeared to remain in the Pacific Ocean until 13 April 2020 when it was again detected at the Golden Gate.

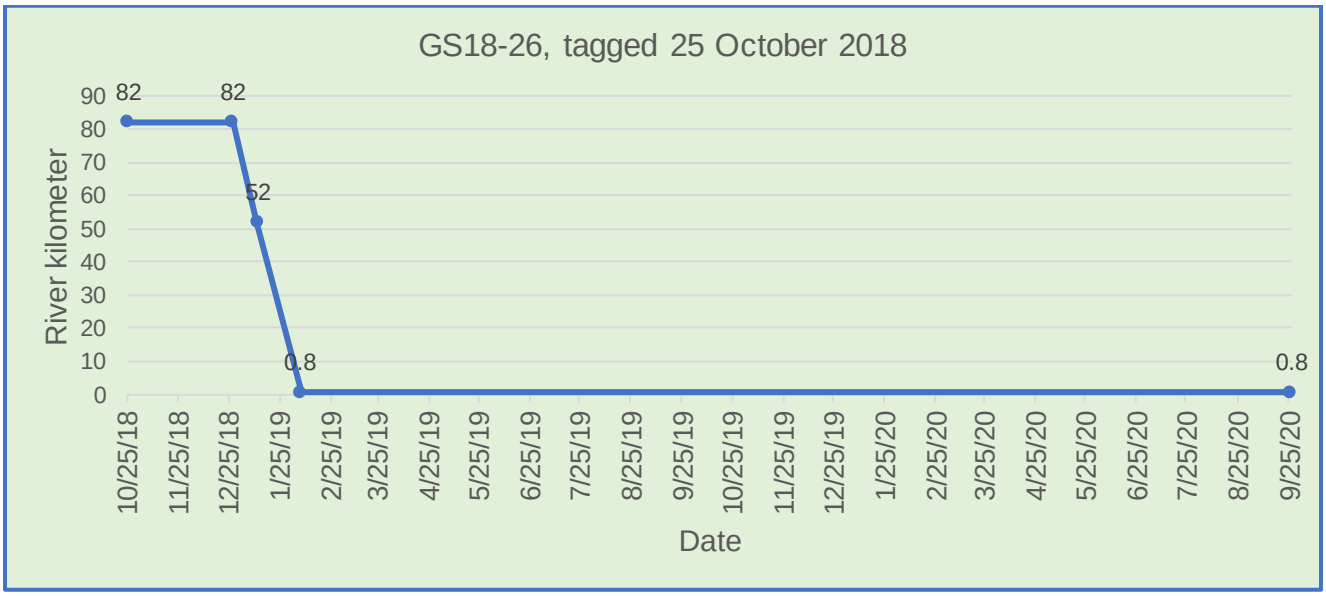

Figure 20. Detection plot for GS18-26; tagged 25 October 2018.

Table 28. GS18-27 Detection Summary. Brood year 2017; Tag code A69-1602-11445; tagged 30 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
11/6 to 2/7/19	No detections	No detections	4/8/19	No detections

Tagging site residency: 93 days. Departure from tagging site to initial detection at the Benicia Bridge: 60 days. Benicia Bridge residency: 1 day.

Table 29. GS18-28 Detection Summary. Brood year 2017; Tag code A69-1602-11437; tagged 31 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/31 to 8/20/19; 912/2019	No detections	No detections	No detections	No detections

Tagging site residency: 293 days.

Table 30. GS18-29 Detection Summary. Brood year 2016; Tag code A69-1602-11452; tagged 6 November 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
11/6/18 to 1/8/19	No detections	No detections	No detections	3/8 to 9/18/19

Tagging site residency: 63 days. Departure from tagging site to initial detection at the Golden Gate: 59 days. Golden Gate residency: 194 days.

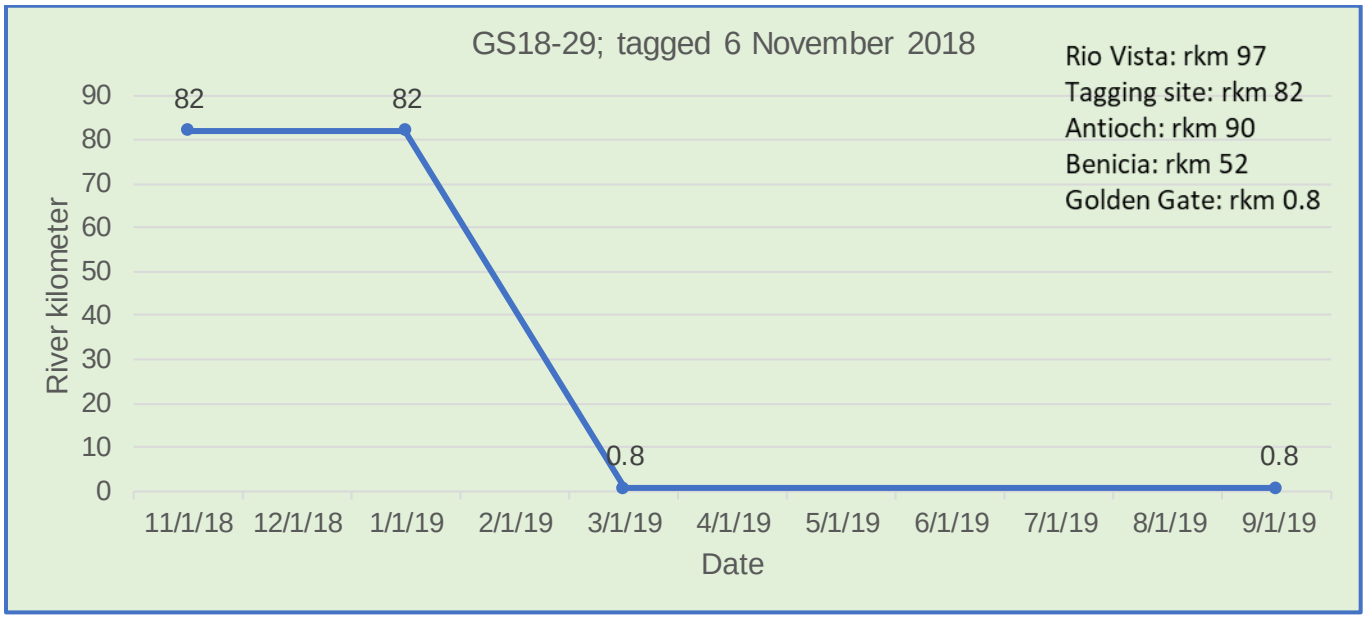

Figure 21. Detection plot for GS18-29; tagged 11 November 2018.

Table 31. GS18-30 Detection Summary. Brood year 2016; Tag code A69-1602-12240; tagged 13 December 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
12/13 to 2/7/19	No detections	No detections	5/2 to 6/14/19	1/12 to 8/6/20

Tagging site residency: 51 days. Departure from tagging site to initial detection at the Benicia Bridge: 84 days. Benicia Bridge residency: 43 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 212 days. Golden Gate residency: 207 days. The initial residency period at the Golden Gate also included a foray into the Pacific Ocean. GS18-30 was detected at the Golden Gate on 15 March 2020; the next detections were at Point San Pedro on 6 to 8 April which is about 28 kilometers south of the Golden Gate. GS18-30 appeared to remain in the Pacific Ocean until 24 April 2020 when it was again detected at the Golden Gate.

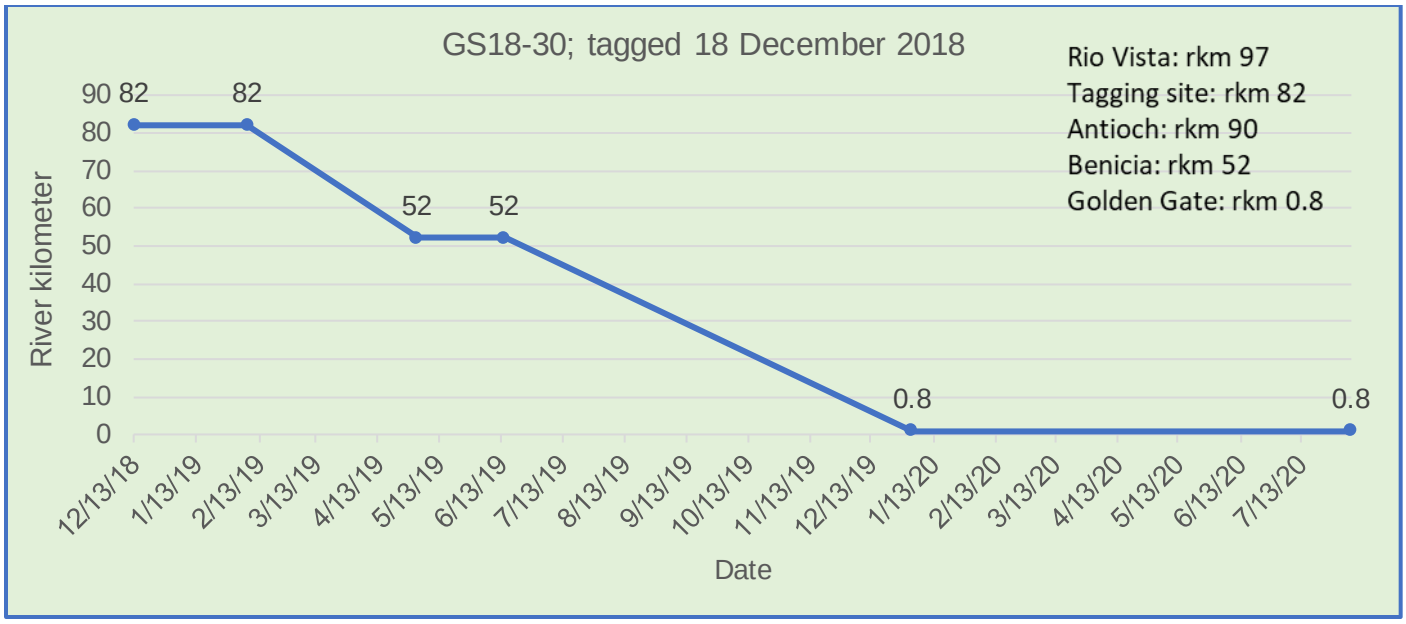

Figure 22. Detection plot for GS18-30; tagged 18 December 2018.

Table 32. GS18-31 Detection Summary. Brood year 2017; Tag code A69-1602-12241; tagged 18 December 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
12/18 to 12/27/18	No detections	8/14/20	1/23 to 5/25/19; 8/17 to 8/19/19	5/31 to 8/3/19; 9/4/19 to 7/4/20

Tagging site residency: 9 days. Departure from tagging site to initial detection at the Benicia Bridge: 27 days. Initial Benicia Bridge residency: 122 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 6 days. Initial Golden Gate residency: 64 days. Departure from the Golden Gate to next detection at the Benica Bridge: 14 days. Second residency at the Benicia Bridge: 2 days. Second departure from the Benicia Bridge to the Golden Gate: 16 days. Second Golden Gate residency: 304 days. The second Golden Gate residency period included a foray into the Pacific Ocean. GS18-31 was detected at the Golden Gate on 7 January 2020. The next series of detections were at the Cement Ship in north Monterey Bay on 14 February and 31 March 2020, Ano Nevo on 21 February and 1 to 2 April 2020, and Point San Pedro in the Pacific Ocean on 3 April 2020. GS18-31 appeared to remain in the Pacific Ocean until 7 April 2020 when it was again detected at the Golden Gate. The final detection for GS18-31 was at the Antioch Bridge receiver array on 14 August 2020.

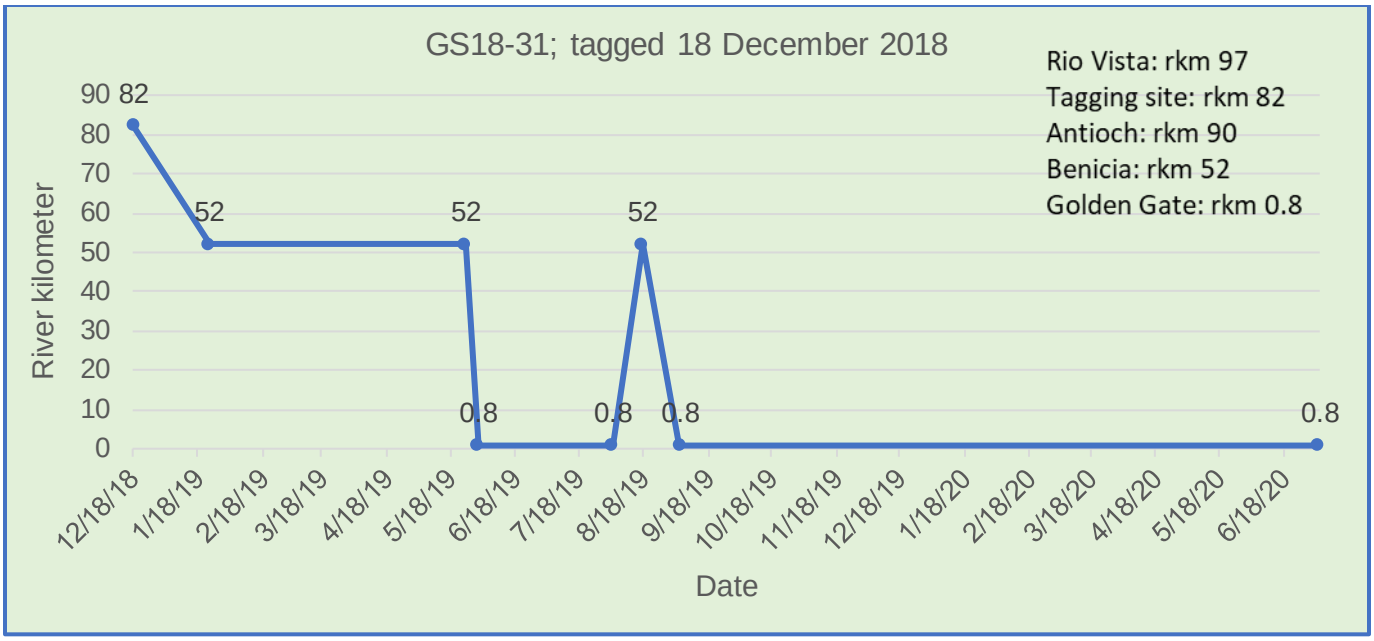

Figure 23. Detection plot for GS18-31; tagged 18 December 2018.

Table 33. GS18-32 Detection Summary. Brood year 2017; Tag code A69-1602-12242; tagged 18 December 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
12/18 to 12/20/18	No detections	No detections	12/26/18 to 1/5/19	No detections

Tagging site residency: 2 days. Departure from tagging site to initial detection at the Benicia Bridge: 6 days. Benicia Bridge residency: 10 days.

Table 34. GS18-33 Detection Summary. Brood year 2017; Tag code A69-1602-12231; tagged 27 December 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
12/27/18 to 12/10/19	No detections	5/7 to 5/17/20	5/20/20	No detections

Tagging site residency: 348 days. Departure from tagging site to initial detection at the Antioch Bridge: 149 days. Antioch Bridge residency: 10 days. Departure from the Antioch Bridge to initial detection at the Benicia Bridge: 3 days. Benicia Bridge residency: 1 day.

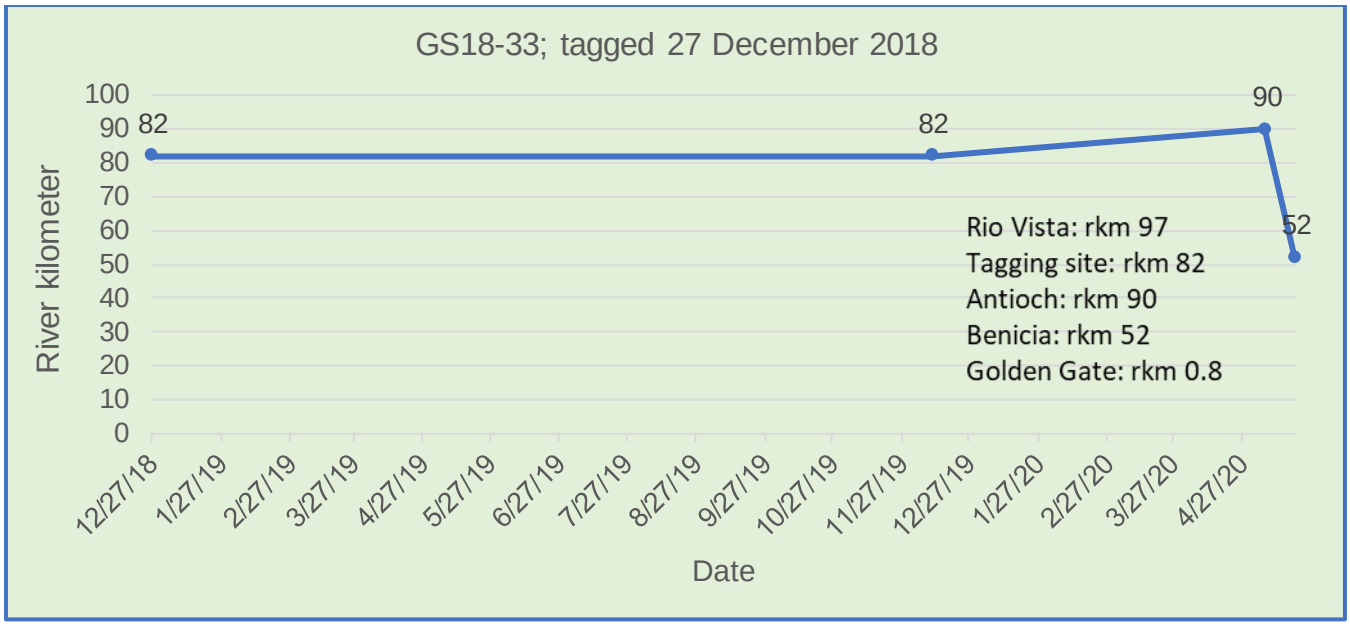

Figure 24. Detection plot for GS18-33; tagged 27 December 2018.

Table 35. GS18-34 Detection Summary. Brood year 2017; Tag code A69-1602-12227; tagged 27 December 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
12/27/18 to 1/15/19	No detections	No detections	3/18 to 6/18/19	9/10/19 to 8/22/20

Tagging site residency: 19 days. Departure from tagging site to initial detection at the Benicia Bridge: 62 days. Benicia Bridge residency: 92 days. Departure from the Benicia Bridge to initial detection at the Golden Gate: 84 days. Golden Gate residency: 347 days.

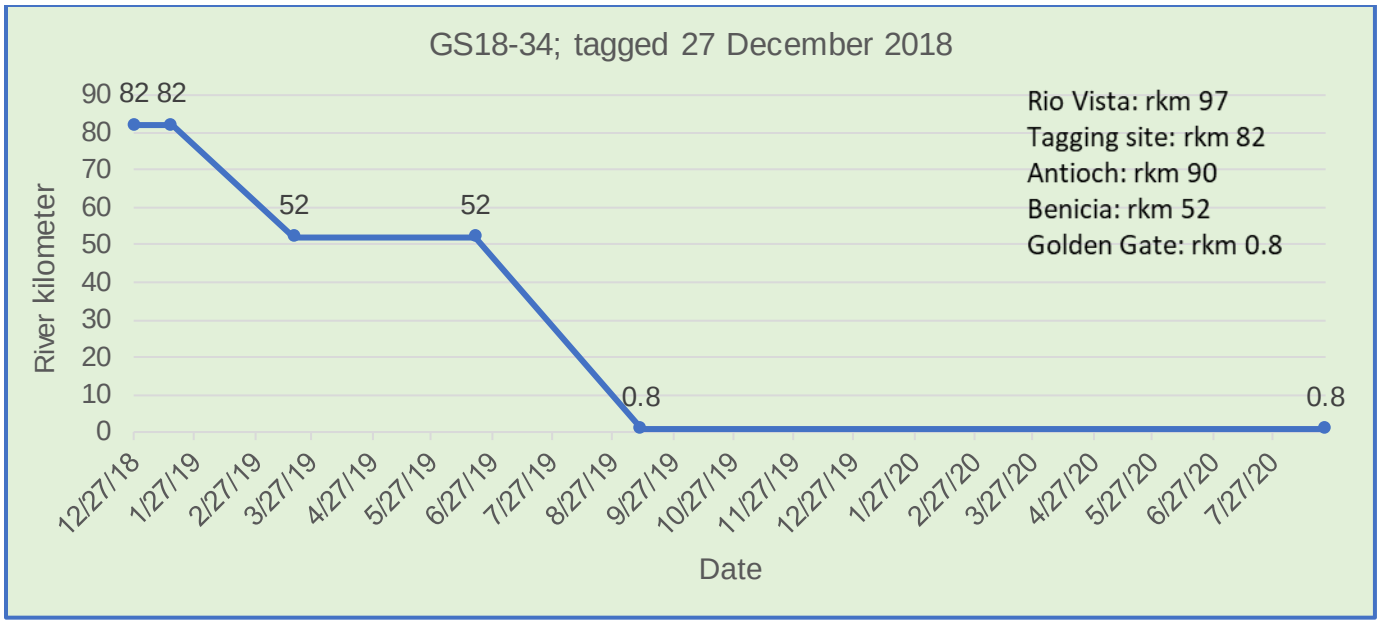

Figure 25. Detection plot for GS18-34; tagged 27 December 2018.

Table 36. GS18-35 Detection Summary. Brood year 2017; Tag code A69-1602-12232; tagged 27 December 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
12/27/18 to 1/3/19	No detections	No detections	No detections	No detections

Tagging site residency: 7 days.

Green sturgeon movement trends. It is important to note that 69 kHz autonomous receivers were not deployed at the sampling site after late December 2017. However, CDFW staff deployed a portable VR100-200 receiver during sampling events, typically for periods of 5-6 hours two days a week beginning in late July of 2018. Thirty-three of 35 juvenile green sturgeon (94.2 percent) tagged with acoustic transmitters were detected for at least one day at the sampling site. The two juvenile green sturgeon that were not detected at the sampling site were also not detected at any other receiver arrays. Residency at the sampling site ranged from one to 348 days, with a mean residency time of 55 days (**Table 42**).

Table 37. Tagging site, Rio Vista Bridge, Antioch Bridge, Benicia Bridge, and Golden Gate initial residency periods and travel times between receiver locations for juvenile green sturgeon tagged in 2018.

Residency (days)									
Tagging site (n=33)		Rio Vista (n=2)		Antioch (n=2)		Benicia (n=20)		Golden Gate (n=20)	
range	mean	range	mean	range	mean	range	mean	range	mean
1 to 348	55	1	1	1	1	1 to 317	63	1 to 554	152

Travel time from tagging site (days)							
Rio Vista (n=2)		Antioch (n=2)		Benicia (n=20)		Golden Gate (n=20)	
range	mean	range	mean	range	mean	range	mean
216 to 313	264	67 to 605	336	3 to 303	99	122 to 487	288

Two of 35 (5.7 percent) juvenile green sturgeon tagged in 2018 were detected at the Rio Vista Bridge receiver array, a distance of 15 km upstream from the sampling site. Days from departure from the sampling site to the initial detection at the Rio Vista Bridge receiver array ranged from 216 to 313 days, with a mean of 264 days. The residency period at the Rio Vista Bridge receiver array for both juvenile green sturgeon was one day. One juvenile green sturgeon, GS18-12, was detected as far downstream as the Benicia Bridge receiver array prior to being detected at the Rio Vista Bridge receiver array.

Two of 35 (5.7 percent) juvenile green sturgeon tagged in 2018 were detected at the Antioch Bridge receiver array on the San Joaquin River (rkm 90 as measured from the Golden Gate). Days from departure from the sampling site to the initial detection at the Antioch Bridge receiver array ranged from 67 to 605 days with a mean of 336 days. Residency at the Antioch Bridge receiver array was one day for both juvenile green sturgeon. GS18-31, which was detected at the Antioch Bridge receiver array 605 days after tagging, was detected as far downstream as the Golden Gate receiver array prior to its detection at the Antioch Bridge receiver array.

Twenty of 35 (57.1 percent) of juvenile green sturgeon tagged in 2018 were detected at the Benicia Bridge receiver array. Days from sampling site departure to the initial detection at the Benicia Bridge receiver array ranged from three to 303 days, with a mean of 99 days. Initial residency at the Benica Bridge receiver array ranged from one to 317 days, with a mean of 63 days. Four juvenile green sturgeon tagged in 2018 had two or more residency periods at the Benicia Bridge receiver array meaning they were detected at one or more receiver arrays after the initial departure from the Benicia Bridge receiver array; one of these, GS18-11, had three residency periods. Second residency periods ranged from one to 12 days, with a mean of 4.2 days. The third residency period for GS18-11 was one day.

Twenty of 35 (57.1 percent) of juvenile green sturgeon tagged in 2018 were detected at the Golden Gate receiver array. Days from sampling site departure to the initial detection at the Golden Gate receiver array ranged from 122 to 487 days, with a mean of 288 days. Initial residency at the Golden Gate receiver array ranged from one to 554 days, with a mean of 152 days. Four juvenile green sturgeon tagged in 2018 had two or more residency periods at the Golden Gate receiver array. All four were subsequently detected at the Benicia Bridge receiver array after their initial departure from the Golden Gate receiver array; the second residency periods ranged from 71 to 304 days with a mean of 195 days, and one juvenile green sturgeon, GS18-11, had four residency periods at the Golden Gate receiver array. The third and fourth residency periods for GS18-11 were both one day residency events.

While the timing of initial detection for juvenile green sturgeon at the Golden Gate array is highly variable, increases in delta outflows may provide a queue for outmigration from the SFBDE (**Figure 26**). Seven juvenile green sturgeon were initially detected at the Golden Gate receiver array from December 2018 through March 2019 when delta outflows increased from a monthly mean of 9,612 cfs in November 2018 to 69,920 cfs in March 2019. However, the other 13 juvenile green sturgeon that were detected at the Golden Gate receiver array had initial detections that occurred during periods of stable, slightly increased, or decreasing Delta outflows, albeit over a much longer time period (September 2018; April 2019 through March 2020). Therefore, increases in Delta outflow may not be the only parameter influencing outmigration.

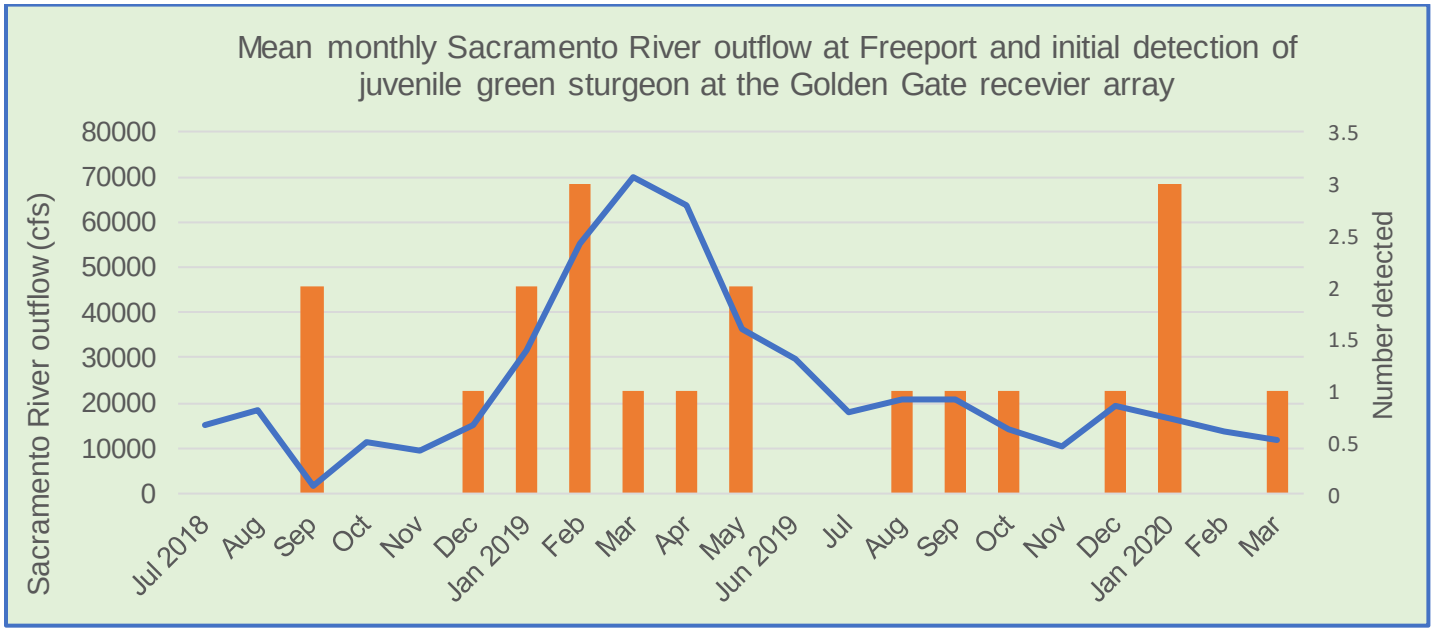

Figure 26. Mean monthly Sacramento River outflow at Freeport and initial detection at the Golden Gate receiver array for juvenile green sturgeon tagged in 2018.

There were no differences in tagging site residency time, travel time from the tagging site to Benicia Bridge receiver array, Benicia Bridge receiver array residency time, travel time from the tagging site to the Golden Gate receiver array, or Golden Gate receiver array residency time based on brood year class, albeit the sample sizes for the 2015 (n=2) and 2016 (n=6) brood year classes were much less than for the 2017 (n=27) brood year classes **(Table 43**). However, the tagging site residency, travel time from the tagging site to initial detection at the Benicia Bridge receiver array, and Benicia Bridge receiver array residency periods for the two 2015 brood year juvenile green sturgeon were much less than for the 2016 and 2017 brood year classes.

69 kHz autonomous receivers deployed in the Pacific Ocean at Point Reyes, Point San Pedro, Ano Nuevo, and Monterey Bay for white shark research recorded detections for six juvenile green sturgeon tagged in 2018: GS18-11, GS18-16, GS18-20, GS18-26, GS18-30, and GS18-31.

Table 38. Juvenile green sturgeon brood year, number tagged, tagging site residency, travel time from tagging site to the Benicia Bridge receiver array, Benicia Bridge (BB) residency, travel time to from tagging site to the Golden Gate (GG) receiver array, and Golden Gate receiver array residency with P-values from ANOVA.

Brood year	Number	tagging site residency (days)	tagging site to BB (days)	BB residency (days)	Tagging site to GG (days)	GG residency (days)
2015	2	1	3	3	208.0	88
2016	6	65.8	36	58.3	154.5	239.2
2017	27	68.7	87.2	78	284.1	135.9
P-value		*0.559*	*0.411*	*0.748*	*0.180*	*0.490*

White Sturgeon.

Table 39. WS18-01 Detection Summary. Brood year 2017; Tag code A69-1601-32411; tagged 2 October 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
10/2 to 10/4/18	No detections	No detections	No detections	No detections

Tagging site residency: 2 days.

Table 40. WS18-02 Detection Summary. Brood year 2015; Tag code A69-1602-11444; tagged 6 November 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
11/6/18; 8/12 to 8/15/19	6/15 to 7/22/19	No detections	11/11/18 to 4/14/19	No detections

Initial tagging site residency: 1 day. Departure from tagging site to initial detection at the Benicia Bridge: 5 days. Initial Benicia Bridge residency: 147 days. Benicia Bridge to initial detection at the Rio Vista Bridge: 120 days. Rio Vista Bridge residency: 37 days. Departure from Rio Vista Bridge to tagging site: 21 days. Second tagging site residency: 3 days.

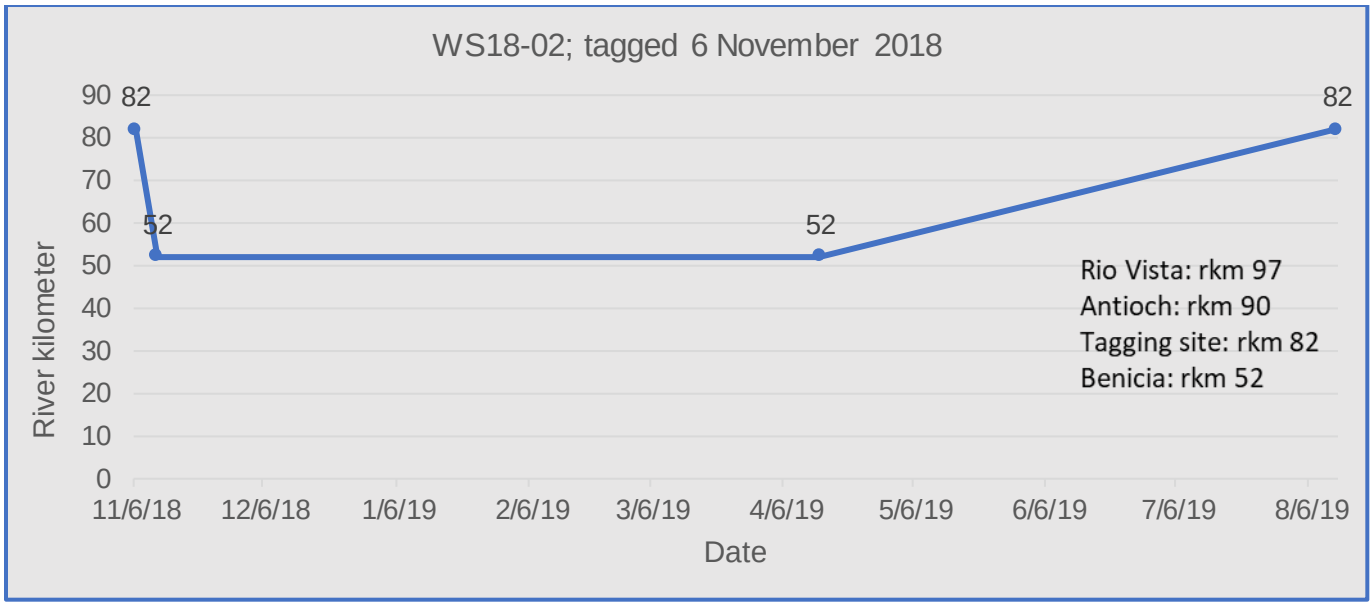

Figure 27. Detection plot for WS18-02; tagged 6 November 2018.

Table 41. WS18-03 Detection Summary. Brood year 2016; Tag code A69-1602-11450; tagged 6 November 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
11/6/18	2/20 to 6/21/19; 6/28 to 7/2/19; 7/27/19	6/22 to 6/24/19; 7/7 to 7/25/19	No detections	No detections

Initial tagging site residency: 1 day. Departure from tagging site to initial detection at the Rio Vista Bridge: 106 days. Initial Rio Vista Bridge residency: 121 days. Rio Vista Bridge departure to initial detection at the Antioch Vista Bridge: 1 day. Initial Antioch Bridge residency: 2 days. Antioch Bridge departure to next detection at Rio Vista Bridge: 4

days. Second Rio Vista Bridge residency: 4 days. Departure from Rio Vista Bridge to next detection at the Antioch Bridge: 5 days. Second tagging Antioch Bridge residency: 18 days. Departure from the Antioch Bridge to next detection at the Rio Vista Bridge: 2 days. Third Rio Vista Bridge residency: 1 day.

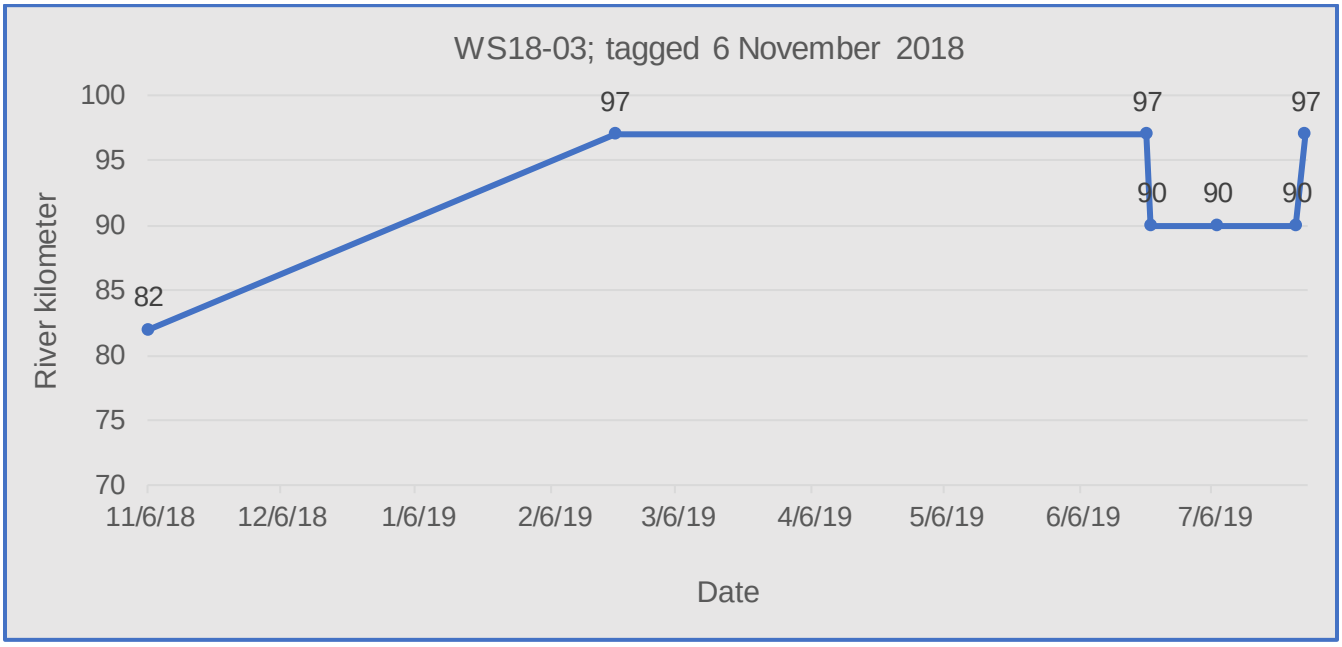

Figure 28. Detection plot for WS18-03; tagged 6 November 2018.

Table 42. WS18-04 Detection Summary. Brood year 2017; Tag code A69-1602-11436; tagged 13 November 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
11/13/18; 8/20 to 9/12/19	5/7 to 5/16/19; 6/2 to 8/17/19	No detections	1/22 to 5/1/19; 5/22 to 5/29/19	No detections

Initial tagging site residency: 1 day. Departure from tagging site to initial detection at the Benicia Bridge: 70 days. Initial Benicia Bridge residency: 99 days. Benicia Bridge departure to initial detection at the Rio Vista Bridge: 6 days. Initial Rio Vista Bridge residency: 9 days. Rio Vista Bridge departure to next detection at the Benicia Bridge: 6 days. Second Benicia Bridge residency: 7 days. Departure from the Benicia Bridge to next detection at the Rio Vista Bridge: 4 days. Departure from the Rio Vista Bridge to the tagging site: 3 days. Second Rio Vista Bridge residency: 78 days. Departure from Rio Vista Bridge to tagging site: 3 days. Second tagging site residency: 23 days.

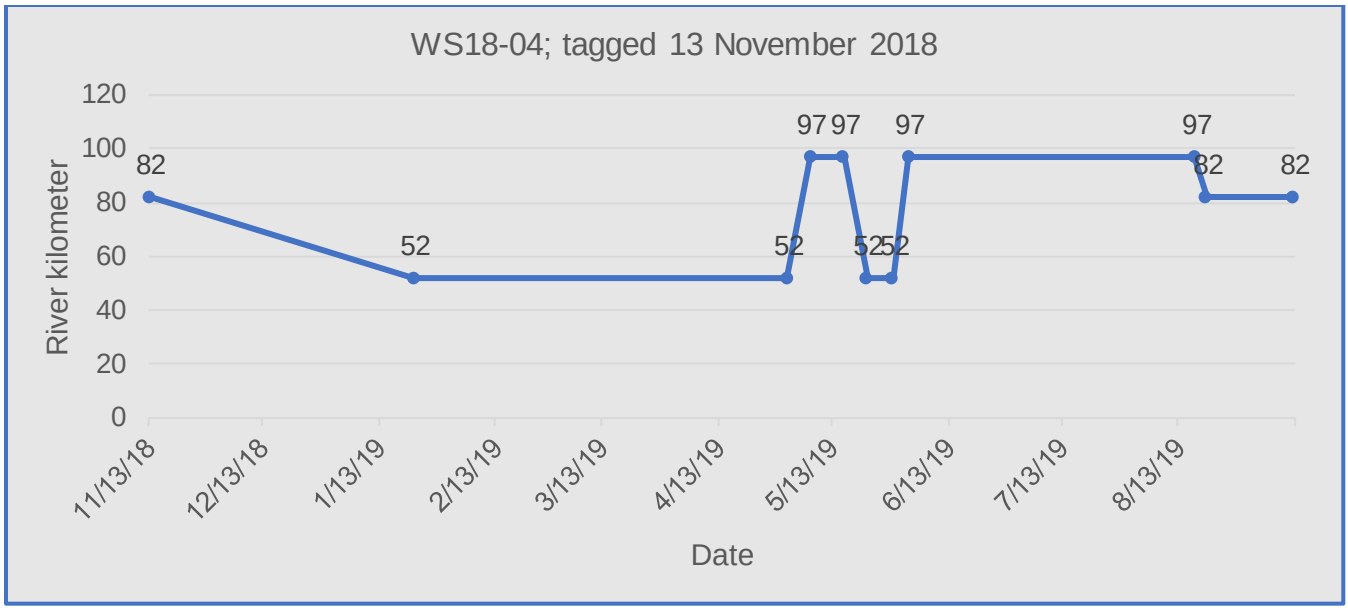

Figure 29. Detection plot for WS18-04; tagged 13 November 2018.

Table 43. WS18-05 Detection Summary. Brood year 2017; Tag code A69-1602-11443; tagged 13 November 2018.

Tagging site (rkm 82)	Rio Vista Bridge (rkm 97)	Antioch Bridge (rkm 90)	Benicia Bridge (rkm 52)	Golden Gate (rkm 0.8)
11/13/18	No detections	No detections	12/4 to 12/8/18	No detections

Tagging site residency: 1 day. Departure from tagging site to initial detection at the Benicia Bridge: 21 days. Benicia Bridge residency: 4 days.

White sturgeon movement trends. All five juvenile white sturgeon tagged in 2018 were detected at least once at the tagging site. Initial residency at the sampling site ranged from one to two days, with a mean residency time of 1.2 days. Two juvenile white sturgeon returned to the vicinity of the sampling site after their initial departure and detection at the Rio Vista or Benicia Bridge receiver arrays. The period between the initial departure and return to the tagging site vicinity ranged from 279 to 280 days with a mean of 279.5 days.

Three of five (60 percent) juvenile white sturgeon tagged in 2018 were detected at the Rio Vista Bridge receiver array, a distance of 15 km upstream from the sampling site. Days from departure from the sampling site to the initial detection at the Rio Vista Bridge receiver array ranged from 106 to 221 days, with a mean of 167 days. The initial residency period at the Rio Vista Bridge receiver array for juvenile white sturgeon ranged from nine to 121 days with a mean of 56 days. WS18-04 had a second residency period of at the Rio Vista Bridge receiver array of 76 days. WS18-03 had second and third residency periods at the Rio Vista Bridge receiver array of four days

and one day, respectively. WS18-03 was the only juvenile white sturgeon detected at the Antioch Bridge receiver array. The initial detection occurred 228 days after departure from the tagging site with a residency period of two days. WS-18-03 also had a second residency period at the Antioch Bridge receiver array of 18 days.

Three of five (60 percent) juvenile white sturgeon tagged in 2018 were detected at the Benicia Bridge receiver array. Days from sampling site departure to the initial detection at the Benicia Bridge receiver array ranged from five to 21 days, with a mean of 15.6 days. Initial residency at the Benica Bridge receiver array ranged from 92 to 151 days, with a mean of 114 days. WS18-04 was the only juvenile white sturgeon tagged in 2018 with a second residency period (four days) at the Benicia Bridge receiver array. No juvenile white sturgeon tagged in 2018 were detected at the Golden Gate receiver array.

Table 44. Tagging site, Rio Vista Bridge, Antioch Bridge, Benicia Bridge, and Golden Gate initial residency periods and travel times between receiver locations for juvenile white sturgeon tagged in 2018.

Residency (days)

Tagging site (n=5)		Rio Vista (n=3)		Antioch (n=1)		Benicia (n=3)	
range	mean	range	mean	range	mean	range	mean
1 to 2	1.2	9 to 121	56	2	2	92 to 151	114

Travel time from tagging site (days)

	Rio Vista (n=2)		Antioch (n=1)		Benicia (n=20)	
	range	mean	range	mean	range	mean
	106 to 221	167	228	228	5 to 21	15.6

Discussion

2018 was the fourth year of this study, and the 2018 CPUE for juvenile green sturgeon was the highest since the beginning of the study in mid-2015 and is likely a result of the wet 2017 water year resulting in high spring and summer Sacramento River and delta outflows which resulted in increased survival of sturgeon eggs and larvae, likely due to decreased predation in each species respective spawning and early rearing habitats. Twenty-eight of 35 juvenile green sturgeon (80 percent) and 3 of five juvenile white sturgeon (60 percent) tagged in 2018 were from the 2017 brood year class. Recruitment of white sturgeon to the juvenile life stage is significantly greater during wet or above normal water years with resulting high delta outflows during late winter through late spring as compared to recruitment during dry or critically dry years with minimal delta outflows (Fish 2010). While there is limited data regarding the recruitment of green sturgeon to the juvenile life stage by water year type, it is likely that green sturgeon exhibit similar patterns. Nine juvenile green sturgeon and one juvenile white sturgeon were detected at the tagging site after release but not at any other receiver locations. A possible explanation is post-release mortality, although all juvenile sturgeon tagged in 2018 appeared to have fully recovered from capture and tagging surgery upon release.

Table 45. Catch per unit effort (CPUE) for 2015 through 2018; 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., 2017 brood year fish recruited from the 2017 water year are Age-1 plus).

Sampling year	Previous water year; classification	Age-1 green sturgeon captured	CPUE	Age-1 white sturgeon captured	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	0.0123

Similar to juvenile green sturgeon tagged in 2016 and 2017, juvenile green sturgeon tagged in 2018 exhibited two distinct movement and rearing patterns in the SFBDE. Some individuals made a more or less linear spatial and temporal migration through the SFBDE prior to ocean entry, while others remained for a longer duration in the SFBDE, making numerous upstream and downstream migrations or foraging forays.

While most juvenile green sturgeon that were detected at the Golden Gate were not subsequently detected at nearshore receivers at Point Reyes, Point San Pedro, Ano Nuevo, and the Cement Ship, or at receiver locations upstream of the Golden Gate, the six juvenile green sturgeon that entered the Pacific Ocean and then returned to the SFBDE provided evidence that juvenile green sturgeon do not necessarily remain in the

marine environment until sexually mature. Returning to the SFBDE or remaining in the marine environment are alternate life history strategies that could increase overall survival of annual cohorts if rearing conditions in either the SFBDE or Pacific Ocean are suboptimal.

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 seven-fold more juvenile green sturgeon than juvenile white sturgeon in 2018 across all brood years encountered. To date, no juvenile white sturgeon tagged in 2016 or 2018 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 presence has not been documented in the Pacific Ocean, although several adult white sturgeon tagged in the SFBDE have been detected as far north as the Columbia River estuary.

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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Attachment A:

JUVENILE STURGEON TAGGING STANDARD OPERATIONAL PROCEDURES

Revised by Marc Beccio
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California Department of Fish and Wildlife
Region 2 Anadromous Fisheries
February 2022

PREPARATION:

1. Prior to conducting field sampling, perform an inventory check on the juvenile sturgeon tagging kit and ensure there everything necessary to conduct tagging is in the surgery kit.

COLLECTION:

1. Upon capture immediately move fish to holding bucket or cooler and place air bubbler in holding tank.

2. Identify species, observe fish condition upon placement in holding container; record capture time and capture location.

SURGERY SET UP:

1. Everything needed to perform the surgery should be included in the juvenile sturgeon tagging kit (see above PREPARATION section).
2. Set up surgery table on a stable platform (e.g., boat deck or captain seat).
3. Fill one five-gallon bucket half-full (10 liters) of river water and add the contents of one pre-weighed vial of MS-222 and mix thoroughly.
4. Fill a second bucket with river water to be used for gravity-feed gill irrigation during surgery.
5. Remove surgery trays and place on surgery bench, collect necessary tools (scalpel, tissue forceps, suture forceps, suture, scissors) and place in trays
6. Weigh and measure sturgeon to determine the appropriate tag size. Record the tag ID and serial number on the data sheet, remove magnet from tag to activate. Check to make sure the identification sticker has been removed from the tag and is taped to the Juvenile Sturgeon Tagging Form

7. Use the PIT tag reader to scan the tag ID and record the ID number on the data sheet.

SURGERY:

1. Place the sturgeon in the anesthesia bucket and monitor the fish for loss of muscle function (torpor). Time to torpor ranges from 45 to 90 seconds.
2. Place the sturgeon on the surgery table and start gravity-feed gill irrigation by placing one end of the 10-mm tube in the sturgeon's mouth. Record total length (TL), fork length (FL), and weight measurements. Measurements can also be made after the completion of surgery. Plan the incision location which should be between the 3-4 ventral scutes off the midline.
3. Make the incision and insert the PIT tag and then the acoustic tag.
4. Use two sutures to close the incision.
5. Make sure all data is recorded on the Juvenile Sturgeon Tagging Form
6. Record surgery end time and place the sturgeon in the holding bucket or tank for recovery. Recovery usually takes less than five minutes, however; the fish should be held in the holding tank until it shows complete recovery (e.g., strong swimming response when held by the caudal peduncle).

7. **Before release, ensure all required data has been recorded on the Juvenile Sturgeon Tagging Form**. The identification sticker that comes with the tag should be attached to the data form as additional insurance that the correct tag identification was recorded on the Juvenile Sturgeon Tagging Form

8. Record the condition of the sturgeon prior to release. The fish should be completely recovered **(see step 6)**

RELEASE:

1. Release the sturgeon either upstream or downstream of the fishing area, considering the direction of current to prevent recapture. Record the release time on the data sheet.