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California Department of Fish and Wildlife

WHITE STURGEON POPULATION MONITORING PROGRAMS

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Anadromous Conservation and Management

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Status assessment of White Sturgeon (*Acipenser transmontanus*) population in the California Central Valley

I. Document Review

This document has been subject to independent peer review by fisheries and sturgeon experts. It reflects changes and suggestions made after comments received by the Department during the review process. A complete list of comments and responses is available in APPENDIX: PEER REVIEW COMMENTS & RESPONSE.

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II. Background

White Sturgeon (*Acipenser transmontanus*) are an anadromous fish species that reside primarily in the San Francisco Bay/Delta and migrate as adults into the major rivers of the Central Valley to spawn. While White Sturgeon support an active recreational fishery, their periodic life-history strategy (late maturation, high fecundity, and episodic spawning) make them highly vulnerable to over exploitation (Chapman et al. 1996; Hildebrand et al. 2016). Successful recruitment is episodic, infrequent, and highly correlated with high spring outflows, with years of little-to-no recruitment punctuated by short periods of high recruitment (Fish 2010). The abundance of legal-sized (most recently, 102 – 152 cm fork length) White Sturgeon has declined considerably over time, and exploitation rates have been higher than what is suggested for sustaining sturgeon populations. Based on mark-recapture data collected by the California Department of Fish and Wildlife (Department), the 2018–2022 5-year average abundance estimate for sturgeon between 102 and 152 cm fork length is ~30,000, representing a precipitous decline from estimates in the late 1990's (~150,000 fish) (CDFW 2023). Despite the adoption of increasingly strict harvest regulations for the fishery, harvest rates remain consistently higher than recommended for sturgeon species (target of 5-10%; Beamesderfer and Farr 1997) and for the population in California (target of <3%; Blackburn et al. 2019). Harvest rate was estimated to average 13.4% from 2007–2015 (Blackburn et al. 2019), and 8.1% from 2016–2021 (CDFW 2023).

White Sturgeon experienced additional mortality during July and August 2022 when a major Harmful Algal Bloom (HAB) of *Heterosigma akashiwo* resulted in significant mortality of fishes from San Pablo to South San Francisco bays. The Department recorded over 850 sturgeon carcasses, the majority legal-sized or larger (CDFW 2023), though it is thought that only a small percentage of the fish killed floated long enough to be detected (e.g. Fox et al. 2020). The absolute magnitude of this impact on the White Sturgeon population is unknown but was likely substantial. In late July 2023, another bloom of *H. akashiwo* returned to San Francisco Bay. The bloom was less intense and of shorter duration than in 2022, but carcasses of 15 White Sturgeon and 1 Green Sturgeon were reported. It is likely that additional HAB induced mortality of fishes including sturgeon will recur in the future, and blooms could be severe depending on environmental conditions.

The Department began monitoring the White Sturgeon fishery using a mark-recapture survey shortly after its re-opening in 1954. These surveys were initially sporadic and infrequent, and due to low capture rates took multiple years of data collection before an abundance estimate could be calculated. For decades, sturgeon were captured using trammel nets and tagged with external disc-dangler tags that anglers were expected to returned to the Department for a reward ($20–$150). The trammel net mesh sizes included 6, 7, and 8 inch stretch and were selected to target fish at and near the legal size for retention (40–60 in. FL). Trammel capture data were used to produce abundance estimates using a Lincoln-Peterson estimator (Ulaski et al. 2023). Starting in 2007, sturgeon anglers in California were also required to fill out a Sturgeon Fishing Report Card and return it at the end of the year, recording the number of fish caught, retained, and released. These additional angler catch metrics allowed the Department to account for harvest numbers and harvest rate, and permitted the use of the Lincoln harvest estimator which is thought to better address the closed population and mark retention assumptions of the earlier Lincoln-Petersen estimate (Ulaski et al. 2023). Both estimators were used between 2007–2016 and in 2021 to compare the methods before the Department shifted predominantly towards the Lincoln-harvest estimator from 2017–2022 (Fig. 1).

The reward tag approach was highly dependent on strong participation from the angling community and risked producing estimates with a high degree of uncertainty when too few tags were returned, while also precluding estimations in some years if tag returns were too low. Additional bias was introduced from the low Sturgeon Report Card (SRC) return rate (~30%, Hause et al. 2023, Figure 2), which contains critical data needed for annual abundance estimates. Further, the trammel net mesh used to capture fish introduced significant gear bias, limiting abundance estimates to "legal sized" fish.

On November 29, 2023, the California Fish and Game Commission (FGC) received a petition to list White Sturgeon as threatened under the California Endangered Species Act (CESA). The petitioners argued that long term declines in the abundance of White Sturgeon are due to 1) Central Valley water management infrastructure and operations, 2) overharvest in the recreational fishery, 3) Harmful Algal Blooms, and 4) other factors such as poaching, pollution, vessel strikes, and climate change. The Department returned an evaluation on March 15, 2024, determining that the petition provided sufficient scientific information to indicate that the petitioned action "may be warranted." On June 19, the FGC voted that white sturgeon warranted candidacy under CESA and directed the Department to initiate a status review of White Sturgeon. At the August 2024 FGC meeting, the Department presented an emergency exemption regulation package under Fish and Game Code Section 2084 that would allow for a catch-and-release fishery during the candidacy period. The FGC voted to approve the Section 2084 exemption, and it went into effect on September 6, 2024.

The Department is currently conducting an in-depth status review of White Sturgeon in California to inform the FGC's ultimate decision on CESA listing. Depending on the outcome, the Department will need to propose long-term regulation and regulatory changes for White Sturgeon to prevent further population declines. These regulations may include harvest, depending on the outcome of the status review and listing decision, and will require more active management of the fishery. Even outside of the impending FGC decision, current abundance estimates using methods that are not biased by low angler participation and tag returns is critical for continued conservation and management of the species for all Californians. Therefore, it is necessary for the Department to develop fishery-independent surveys for monitoring population dynamics of White Sturgeon to more accurately and effectively set these targets for the fishery. To this end, the Department has developed two new projects: (1) a mark-recapture survey to evaluate the population abundance in the California Central Valley, and (2) a spawning assessment of White Sturgeon in the California Central Valley. In addition, the Department will take advantage of reliable access to adult fish in the setline program and will surgically insert acoustic telemetry tags into a subset of captured fish. These tags can be detected by receivers operated by the Department and by the large shared acoustic telemetry array in the Central Valley which will provide a wealth of information on migration timing, spawning and holding habitat, residence times, population structure, and alternative behavioral strategies.

III. Population assessment of White Sturgeon in the California Central Valley using setline mark-recapture

Questions addressed

1. What is the absolute abundance of subadult and adult White Sturgeon in the San Francisco Estuary?
2. What is the population age distribution, size structure and body condition of White Sturgeon in the San Francisco Estuary?
3. What is the relative spatial distribution of White Sturgeon in the San Francisco Estuary?

Methods

Setline surveys have been demonstrated as a low cost and effective means of capturing White Sturgeon of a range of sizes in the Columbia River and San Francisco Estuary (SFE, Elliot and Beamesderfer 1990; Dubois et al. 2010). When tested against gill nets and angling as a sturgeon capture method in the Columbia River, researchers found that setlines provided a balance between catch rates, size and species selection, and mortality (Hannevig 2020). Setlines are long lines with multiple baited hooks attached to two anchor points and left submerged to fish for a predetermined amount of time. Deploying setlines to successfully catch sturgeon requires a fishing or research vessel outfitted with the appropriate equipment, including a side roller with a power winch. The Department does not have available vessels that meet the necessary requirements; therefore, three boats and captains will be contracted to perform the survey. Boats will be crewed with 4 people, including 1 boat operator, 1 deck hand, 1 biologist and 1 technician.

To balance spatial coverage and the probability of contacting sturgeon within the constraints of survey resources, we leveraged Sturgeon Report Card (SRC) data to inform the spatial extent of the setline survey. We chose the four SRC location codes associated with the highest proportion of total reported catch, as well as the intervening regions, as the total survey region. We then limited the survey area to sampleable depths >4 ft at mean lower low water (MLLW) to ensure that setlines are not deployed in areas where they could inadvertently become dewatered due to tidal action or otherwise become unrecoverable. This resulted in a total surveyable area of 261 km^2 and included SRC location codes (i.e., zones) 4, 9, 10, 16, 17, 18, and 19 (Fig. 3; Hause et al. 2023).

Each survey includes two 8-week stages, a "marking period" from April–May and a "recapture period" from August-September, with two months in between to allow tagged sturgeon to redistribute in the environment. These dates were selected to avoid overlapping with the spawning migration. The Department does not want to handle and stress fish that are preparing to spawn in late fall and early winter, and fish that migrate into the river to spawn in the spring would be considered to have emigrated from the survey area, violating the closed population assumption of the estimation methods. In the marking period, the goal is to maximize the number of sturgeon tagged while maintaining broad and balanced spatial coverage. Power analysis indicates that tagging 1400 fish during the marking phase each year would be sufficient to estimate abundance with a 10% confidence interval. All zones will be sampled to achieve spatial coverage; however, the locations within zones and the frequency of visits to each sampling location will be adjusted *ad hoc* to maximize the number of White Sturgeon tagged.

For the recapture period, each survey zone is divided into 9 km^2 survey units (Fig. 4). Units within zones are drawn randomly using the Generalized Random Tessellation Stratified (GRTS, Dumelle et al. 2023) algorithm weighted by the sum of scaled sampleable surface area of each zone and, in the first year, scaled catch as reported on SRCs. Future weighted scaling will be based on the proportional catch per unit effort observed during the previous years' setline operations. The main purpose of creating a spatially balanced recapture sampling scheme is to reduce spatial bias in population abundance estimates and relative abundance indices. Furthermore, weighting factors incorporate the variability in the distribution of sturgeon into the random sampling process, thus increasing the probability of selecting sampling units that contain sturgeon. Over the 8-week recapture period, 9 survey units will be sampled each week over a total of 32–40 survey days.

Setline deployment and White Sturgeon tagging protocols will follow Hannevig (2020) for both the both the marking and recapture period. In brief, methods are as follows:

1. Setlines will be constructed from 600 ft of ¼ inch tarred mainline terminated with eye splices. These lines will be marked at 15 ft intervals.

2. A float line of appropriate length for a given depth will be attached to mainline at starting end of setline.

3. When directly over a sampling site, the float will be tossed overboard and the anchor lowered as one person pays out the mainline and the other attaches pre-baited gangions to the mainline at 15 ft. intervals. Gangions are assembled using a stainless steel longline snap with a 6/0 swivel, an approximately 16-inch leader made of nylon twine, and an attached 16/0, 14/0 or 12/0 hook. When the longline is lowered, a deployment start time will be recorded.

4. When nearly all the line has been deployed, the second anchor and float line will be attached to the opposite end of the mainline and lowered to the bottom. The deployment end time and GPS coordinate will be recorded when the second buoy is tossed overboard.

5. After an approximately 24-hour soaking period, the setline will be retrieved starting from the downstream float. The buoy and float line will be brought aboard, the float line will be routed through an electric line puller, and the retrieval end time recorded.

6. Fish will be removed from the hooks as they are retrieved and gently placed in an aerated, flow through live well until the entire set is pulled.

7. All incidental catch (i.e., bycatch) will be recorded (including species, length, and sex if possible) and returned to the water.

8. Sturgeon will be examined for tags, tag scars, fin marks, scute marks, and surgery scars and then scanned for PIT tags.

9. Fork length and girth will be recorded to the nearest centimeter and a pit tag will be injected behind and beneath the bony plates of the head. Weight will be recorded to the nearest kg and the PIT tag code will be read and recorded. The second left lateral scute will be removed from all PIT tagged fish, which is a permanent external mark that does not seem to affect recapture rate (Rien et al. 1992)

10. After recovery, the condition of the fish will be recorded and the fish released. Condition categories:

    a. Good: Fish is active and vigorous, strong gill movements, and has no significant injuries, abrasions, fin damage. Fish swims away vigorously when released.

    b. Fair: Fish is alive but not vigorous. Some degree of minor injury is present. May be slow to swim away immediately but revives quickly.

    c. Poor: Fish is sluggish or inert, though some gill movement is visible. Significant wounds, bruising, abrasion, and/or fin damage. Does not swim away vigorously when released, instead it floats or sinks.

    d. Mortality: Fish was either dead upon retrieval or did not survive processing.

Analyses of setline data will include but are not limited to (1) estimating size selectivity of the gear and (2) estimating relative and population abundance. Quantifying and correcting for selectivity of fishing gear, represented as a probability of capturing a certain size of fish on a particular size of gear, is critical for accurately estimating population size structure. Size selectivity of the fishing gear targeting White Sturgeon in the San Francisco Estuary will be estimated according to methods in Hovgård and Lassen (2000), wherein the most appropriate selection curve is identified based on the proportion of size classes caught during the mark-recapture survey, and the catch adjusted accordingly. Catch data from the setline survey will be used to establish a relative abundance index, as well as calculate total catch, catch per hook hour, spatial distribution of catch (catch per unit effort by zone), and size structure of the population (relative catch by size class). The relative abundance index can be used to identify relative distribution of sturgeon across the study area and will be calculated based on the following catch per unit effort (CPUE) equation:

$$CPUE = \frac{(Sturgeon\ Count)}{(Total\ Hooks * Hours\ Fished)}$$

A length-weight regression will be used to compare relative condition of sturgeon based on catch location, date of capture, sex, and stage at maturity.

Recapture data from the first year will be used to estimate population abundance ($\hat{N}$) using the Chapman-modified Lincoln-Petersen method (Lincoln 1930; Petersen 1896; Seber 1982), following the equation

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1$$

where n_1 is the number of sturgeon caught and tagged during the first sampling period, $n_2$is the number of sturgeon caught during the second sampling period, and m_2 is the number of marked sturgeon captured during the second sampling period. The Lincoln-Petersen method assumes that 1) the population is closed to mortality, immigration, and emigration; 2) that there is an equal likelihood of capture across all individuals; 3) that the probability of capture is random; and 4) that all marks are retained and correctly observed. Assumptions 3 and 4 are addressed by the study design. Intramuscular PIT tags have a very high retention rate and low failure rate and are expected to last the life of the fish, and the sampling regime is randomized. The assumption of equal probability of capture may be influenced by gear selectivity bias, but this should be mitigated by the use of three different hook sizes and will be further refined as data accumulate and catch-curves can be developed. The assumption of a closed population is not met. Fish may emigrate or immigrate from the rivers or ocean into the open San Francisco Estuary, and some harvest was permitted during the mark phase and partially into the redistribution phase in 2024 (the fishery is now closed to harvest indefinitely). This violation of a closed population has been minimized by the study design. The survey timing was selected to correspond with the period when telemetry data indicate that White Sturgeon are not present in the rivers, while ocean migration is believed to be rare. Unfortunately, we do not know the extent of routine movements to South Bay and the interior Delta, which are outside of the study area, or the rate of natural mortality; however, this is minimized by a short 1-2 month redistribution period between the mark and recapture phases. Given these challenges, the Lincoln-Petersen estimate has been identified as the most appropriate closed population model to use given the timing and effort the Department can put towards the survey, and analysis indicates that catch probability during the 2024 pilot study was high enough (~0.047) to avoid overestimation.

In future years, continued sampling will allow for the adoption of Pollock's Robust Design (Pollock 1982), which combines the additive-capture Cormack-

Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) with the use of closed population models. This method requires one “primary sample” period each year to use in an open-population year-to-year model (CJS) and multiple within-year capture events to inform the closed population model (in our case, Lincoln-Petersen). The CJS model will be used to calculate year-to-year abundance estimates ($\widehat{N}_i$), capture probability estimates ($\hat{p}_i$), survival estimates ($\widehat{\varphi}_i$) and recruitment through births and immigration ($\hat{B}_i$) will be calculated using the following equations (Hayes et al. 2007):

$$\widehat{M}_i = m_i + \frac{R_i z_i}{r_i}$$

$$\widehat{N}_i = \frac{n_i \widehat{M}_i}{m_i}$$

$$\hat{p}_i = \frac{m_i}{\widehat{M}_i}$$

$$\varphi_i = \frac{M_i + 1}{\widehat{M}_i - m_i + R_i}$$

$$\hat{B}_i = \widehat{N}_{i+1} - \hat{\varphi}_i(\widehat{N}_i - n_i + R_i)$$

Where M_i is the number of sturgeon tagged at the beginning of the sample; $\widehat{M}_i$ represents an estimate of marked individuals available for recapture during sample *i*, m_i is the number of sturgeon tagged in the *i*th sample; n_i is the number of fish caught in the *i*th sample; R_i is the number of fish caught in the *i*th sample that are tagged and released; z_i is the number of fish caught before the *i*th sample that are not captured in the *i*th sample but are caught during a later period; and r_i is the number of fish released at the *i*th sample that are later recaptured. As an open population model, CJS is not susceptible to the same assumption of a closed population as the Lincoln-Petersen model; it does, however, require multiple years of data to be implemented.

Over the first couple of years, this project will be a pilot study to identify the best method for catching White Sturgeon in the study area using setlines. This means that standardization of gear, specifically bait, will likely not occur until Year 3. In addition, the assemblage of other fish species that can affect catch rate of White Sturgeon differs between San Pablo Bay compared to elsewhere in the study area. Both inconsistencies may violate the assumption of equal catch probability inherent to mark-recapture studies. This will be resolved as we collect data to inform spatial catch probabilities and standardize our gear going forward.

Data collected in sequential years will be used to track changes in estimated population abundance, relative spatial distribution, relative population size structure, and changes in body condition.

Timeline

April 2024	Gear preparation
May 2024	Mark Phase 1 Month 1
June 2024	Mark Phase 1 Month 2
July 2024	Dispersal
August 2024	Recapture Phase 1 Month 1
September 2024	Recapture Phase 1 Month 2
October 2024	Data QC
November 2024	Lincoln-Petersen Analysis
December 2024	-
January 2025	Gear Maintenance, Purchasing
February 2025	Gear Maintenance, Bait Preparation
March 2025	Gear Maintenance, Bait Preparation
April 2025	Mark Phase 2 Month 1
May 2025	Mark Phase 2 Month 2
June 2025	Dispersal
July 2025	Dispersal
August 2025	Recapture Phase 2 Month 1
September 2025	Recapture Phase 2 Month 2
October 2025	Data QC

November 2025	Cormack-Jolly-Seber Analysis
December 2025	Summary Report 1

IV. Spawning assessment of White Sturgeon in the California Central Valley

Questions

1) What is the relative abundance of spawning White Sturgeon in the Sacramento and San Joaquin rivers?
2) Where do spawning White Sturgeon aggregate in the Sacramento and San Joaquin rivers?
3) Does an N-Mixture model created using spawner enumeration provide an accurate abundance estimate of White Sturgeon in the California Central Valley?

Methods

The sonar survey component of this project will entail the use of recreational grade side-scan sonar to generate White Sturgeon spawning indices in the Sacramento and San Joaquin rivers. Survey methods will closely follow those adopted by the National Marine Fisheries Service for assessing spawner abundance of Green Sturgeon in the Sacramento River (Dudley and Battaile, n.d.; Battaile et al. 2024). Due to the large size and distinct body shape of sturgeon, sidescan sonar has been shown to be an effective tool for rapidly surveying spawning adults in large expanses of river, requiring fewer passes and less time than alternative methods such as ARIS/DIDSON acoustic imaging cameras.

Sampling will be conducted as two separate approximately seven-day surveys per year, once in March and once in April. The sample timeframe is based on White Sturgeon telemetry studies and egg mat surveys (Jackson et al. 2016; Miller et al. 2020; Schaffter 1997), which indicate peak residence for White Sturgeon in the spawning reach is in March and April, with eggs detected in late March through early May. While Green Sturgeon are present and potentially spawning during this same general time period, they more typically spawn later in the season (May-July) and segregate spatially (Heublein et al. 2009; Poytress et al. 2015), minimizing potential species misidentification. That said, species identification between Green and White sturgeon is very difficult when relying on sonar imagery: to estimate the number of Green Sturgeon that may concurrently overlap with White Sturgeon in the study area, conventional high-resolution underwater video cameras will be used to attempt to distinguish between the two species.

White Sturgeon spawning has been positively recorded on the Sacramento River from Colusa (river kilometer (rkm) 232) to Verona (rkm 129) (Schaffter 1997) and confirmed by egg mat surveys conducted by CDFW North Central Region (M. Beccio, personal communication). As such, the spawner survey reach on the Sacramento River will begin at rkm 80 and extend upstream to rkm 281 (Figure 5). The upstream end of the survey reach is extended beyond Colusa to account for potentially unknown spawning locations, anecdotal observations of White Sturgeon upstream of Colusa, and to meet the downstream extent of the NMFS Green Sturgeon spawner survey. On the San Joaquin River, surveys will be conducted between rkm 115 and 138 based on collection of White Sturgeon eggs in this reach (Jackson et al. 2016) (Figure 5).

Surveys will involve conducting three digitally recorded passes of the bottom structure using a properly calibrated side scan sonar unit (Hummingbird Apex 13 or similar). If more than five sturgeon are observed in a given site, then two more passes will be conducted to ensure adequate coverage and image resolution. All habitat greater than 5m depth will be surveyed, skipping shallow areas where White Sturgeon are unlikely to hold to maximize time efficiency. Sonar imagery will be collected in a downstream direction at a speed of 4-5mph to minimize the effects of water disturbance and general turbulence on image quality.

Once a survey has been completed (Sacramento River km 80-281, San Joaquin River km 115-138), sonar images will be stitched into a georeferenced mosaic for analysis using SonarTRX or similar software. Sonar mosaics will be manually and independently processed by two staff to determine the number of White Sturgeon present at each recorded location. Counts will be compared between staff to ensure data quality. These counts will be used to create indices of spawner abundance, with the relative population distribution used to identify spawning aggregation sites.

Similarly to Battaile et al. (2024), this study will attempt to use the confirmed White Sturgeon spawning counts to estimate population abundance using N-mixture models utilizing telemetry data and environmental covariates collected in the field, with the benefit of being able to compare the resulting abundance estimate to those made in the mark-recapture survey. N-mixture models provide a robust framework for estimating absolute population abundance by accounting for detection probability and mean abundance as observed in repeated counts across many sites. N-mixture models assume that the population is closed, that the detection probability is the same for all individuals, and that there are no false-positive identifications. Given the short sampling period and fishery closure in the spawning areas, the first assumption of a closed population should be met. The large field of view provided by sonar side scanners coupled with multiple passes to distinguish between large, live fish and their surrounding environment by their shape, position in the water column, and behavior should likewise resolve the assumption of consistent detection probability. This leaves possible misidentification as the remaining assumption violation due to the potential overlap of Green and White Sturgeon. This may be addressed by confirming species identification using ARIS and traditional underwater footage, and subsequently estimating the number of Green Sturgeon present, but we will not know how successful this is until the first season is over.

Timeline

January 2025	Gear Purchasing
February 2025	Gear Assembly
March 2025	Sampling Event 1 (1-week)
April 2025	Sampling Event 2 (1-week)
May 2025	-
June 2025	Sturgeon enumeration
July 2025	Sturgeon enumeration
August 2025	-
September 2025	-
October 2025	Sturgeon Enumeration
November 2025	White Sturgeon Spawning Index 1

V. Sturgeon Telemetry

White Sturgeon are highly mobile, powerful swimmers that have the ability to move easily between freshwater and saltwater environments, resulting in complex movement and migration patterns. Acoustic telemetry has permitted researchers to study the timing and periodicity of movements, and study habitat use in the San Francisco Estuary and into the Sacramento River (e.g. Miller et al. 2020). More recently, microchemical analysis has identified at least four distinct movement strategies between the various salinity gradients present within the San Francisco Estuary (Sellheim et al. 2022). During the first 10 years of life, one cohort of fish remained in the freshwater delta, another cohort moved quickly to saline areas and remained there, and the other cohorts employed intermediate strategies, moving between fresh and saline regions. Such a wide range in behavioral characteristics suggests a portfolio effect, in which populations evolve to express different suites of behavior under different conditions to cope with uncertainty in their environment.

In California, White Sturgeon reside primarily in the San Francisco Bay/Delta and migrate as adults into the major rivers of the Central Valley to spawn. Their occurrence in this region overlaps with significant anthropogenic alterations in terms of water management, land use development, structural impoundments, fertilizer and chemical dispersal, industrial and recreational use, and rapid environmental variations resulting from climate change. These factors are all able to alter the timing, duration, speed and periodicity of fish movement, and can adversely affect anadromous fishes such as White Sturgeon. These factors can also influence the reproductive biology in sturgeon, altering the speed, timing, and duration of gonadal development, fecundity, and lead to abnormal physical development. In particular, White Sturgeon in SFE show evidence of intermediate levels of contaminant exposure to toxins that can disrupt or alter physical development (including mercury, polychlorinated biphenyls, polybrominated biphenyl ethers, and selenium), with exposure levels and accumulation varied based on size, diet and movement (Greenfield et al. 2003; Gundersen et al. 2017). For these reasons, monitoring White Sturgeon movement behavior and gonadal development in the California Central Valley remains an important facet in assessing the impact of continued anthropogenic alterations and directing management priorities for the species.

While prior attempts at assessing White Sturgeon movement in the California Central Valley have been successful in establishing broad migratory timing and identifying unique movement patterns expressed by White Sturgeon in certain areas, they have been somewhat limited by short temporal scales, relatively small population coverage, selective biases towards specimens from particular areas or age classes, and the difficulty in delineating between sexes using non-invasive methods. Recently adopted methods used by the contemporary White Sturgeon mark-recapture survey have proven very effective at capturing a large number of sturgeon across a wide range of age classes as they occur in San Pablo Bay, the Napa River, Suisun Bay and the lower Sacramento River. The Department plans to leverage the capture efficiency and coverage breadth of the mark-recapture study to acoustically tag a significantly larger number of fish than in any previous White Sturgeon telemetry studies, across a wider area, with increased effort in identifying the sex, stage of maturity, and gonad structure of each individual. As an increasing number of the population become tagged, this information can be used to better refine our understanding of White Sturgeon migration patterns and movement behaviors, incorporate their movement dynamics within our population models, identify environmental conditions that are potentially harmful to reproductive development, inform management and conservation priorities alongside largescale infrastructure projects, and to track aberrant behavior that may arise from changes in environmental conditions in near-real-time.

Questions

1. Are there distinct migratory patterns and movement behaviors across population segments of White Sturgeon in the San Francisco Estuary?
2. Is there a difference in spatial distribution and migration timing of White Sturgeon based on sex?
3. What is the spawning interval and maturation cycle of White Sturgeon in the California Central Valley?
4. Are there differences in gonadal development based on movement across different regions and environmental gradients?

Method

To monitor movement patterns and migration, we propose surgically implanting acoustic tags to a subset of between three and five of the White Sturgeon captured during the setline study on each boat each day, for a total of nine to fifteen novel acoustic tags deployed each day. This will result in a total of 144 to

240 tags each season, with a target of approximately 5% of the current estimated population tagged within 5 years. These tags can persist for 10 years and will provide a long-term telemetry dataset to monitor White Sturgeon behavior through different climate cycles, development actions and flow regimes.

Acoustic tags (Innovasea V16) will be surgically implanted into the peritoneal cavity of subadult and adult White Sturgeon (87–200+ cm FL). Sturgeon will be inverted in a cradle, their head and eyes covered, and their gills continuously ventilated with water. A 2–3 cm incision will be made adjacent to the third or fourth ventral scute, offset from the midline. An otoscope will be inserted into the incision to view gonadal tissue for identifying the sex of the specimen. An endoscope will be used to capture a picture of gonadal tissue, and a biopsy sample will be taken of the gonadal tissue. A sterilized tag will then be inserted and the incision closed with 2–4 individually knotted, dissolving sutures. The biopsy samples will be labeled and placed in 10% phosphate-buffered formalin solution for storage before being sent to the USFWS Bozeman Fish Technology Center, MT, to be prepared for histological examination following standard methods described in Luna (1968). Broadly, this involves embedding tissues in paraffin wax, staining them, sectioning them, and then examining those sections under a compound microscope. Histological examination and photos will be used to confirm the sex of each tagged sturgeon. Histology of the biopsy tissue will provide information on stage of development following the scoring criteria described by Van Eenennaam and Doroshov (1998) as well as to determine the presence of structural abnormalities, macrophage aggregates and lymphocyte levels. This can be indicative of age and exposure to toxins that can disrupt the endocrine system.

Movement behavior and migration pattern of White Sturgeon will be assessed based on their movement timing and distribution recorded from detections from acoustic receivers maintained by CDFW and the multiagency California Central Valley core array. This array is widely dispersed from the Golden Gate Bridge in San Francisco Bay and up both the Sacramento and San Joaquin rivers and can allow tracking of movement using data from the UC Davis Pacific Aquatic Telemetry Hub (PATH). Movement behavior will be classified based on dominant regional occupancy and the timing and duration of movements. Mixed effect models will be used to determine if there is a difference in mean sex ratio between sturgeon movement classifications or capture regions. Path analysis will be used to identify variables that drive the timing and periodicity of movement throughout the Central Valley based on environmental variables such as temperature, salinity, and discharge.

The spawning interval and maturation cycle of White Sturgeon in the California Central Valley will be determined based on histological analysis of gonadal tissues. Path analysis will be used to identify correlations between the observed gonad development stage and structural condition determined by the histological examination based on the salinity, temperature, and region that the individual was captured. Ultimately, these gonad development and structural characteristics will be related to the long-term movement classifications identified by the telemetry data collected in PATH. One-way analysis of variance (ANOVA) will be used to determine if there is a difference ($p > 0.05$) in mean stage of maturation, sex ratio, and presence of structural abnormalities in White Sturgeon based on movement classification and capture region.

Timeline

January 2025	Gear Purchasing
February 2025	Gear Assembly
March 2025	
April 2025	Capture Event 1
May 2025	Capture Event 1
June 2025	
July 2025	
August 2025	Capture Event 2
September 2025	Capture Event 2
October 2025	Send samples to Bozeman Fish Technology Center; PATH tracking
November 2025	PATH tracking
December 2025	PATH tracking
January 2026	PATH tracking
February 2026	PATH tracking

March 2026	PATH tracking
April 2026	PATH tracking
May 2026	Capture Event 3
June 2026	Capture Event 3
July 2026	Path analysis
August 2026	Capture Event 4
September 2026	Capture Event 4
October 2026	Send samples to Bozeman Fish Technology Center; PATH tracking
November 2026	PATH tracking
December 2026	Year 1 summary report; PATH tracking

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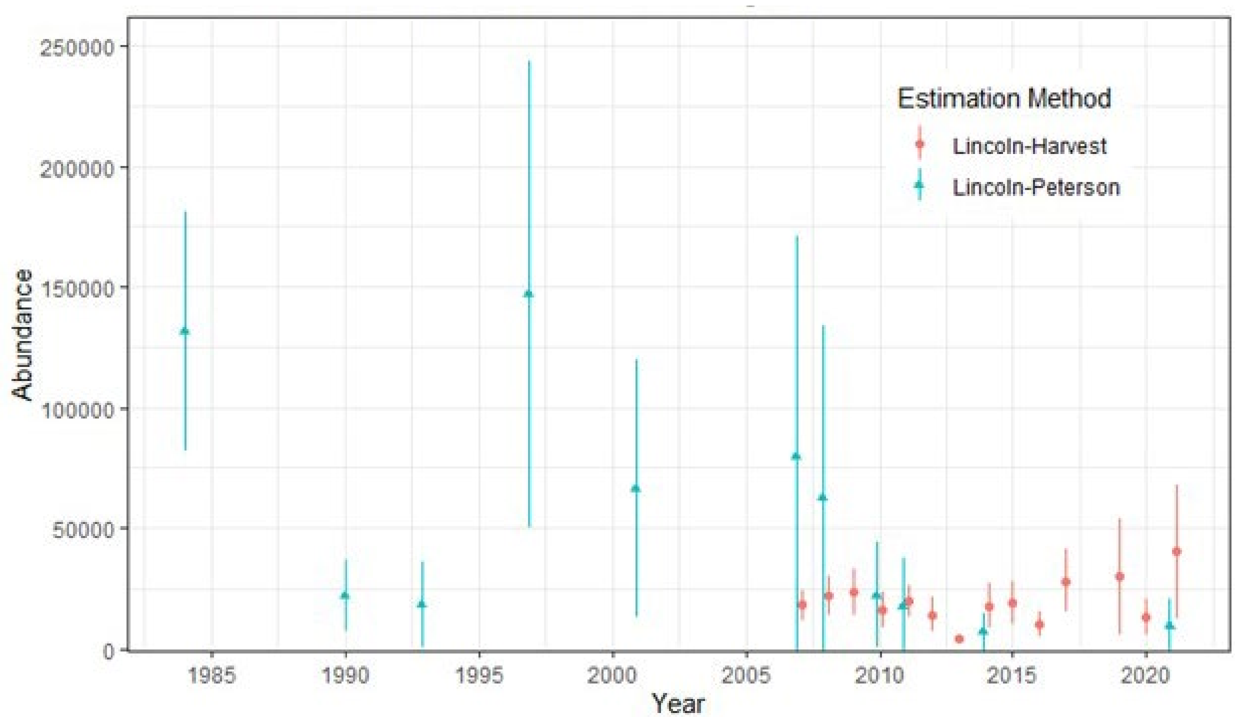

Figure 1. Estimated number of 40 to 60 inch White Sturgeon between 1984 and 2021. Blue/triangle points represent estimates made using the Lincoln-Peterson method, red/circle points represent estimates made using the Lincoln-Harvest method. Vertical lines are the 95% confidence interval around the mean point estimate.

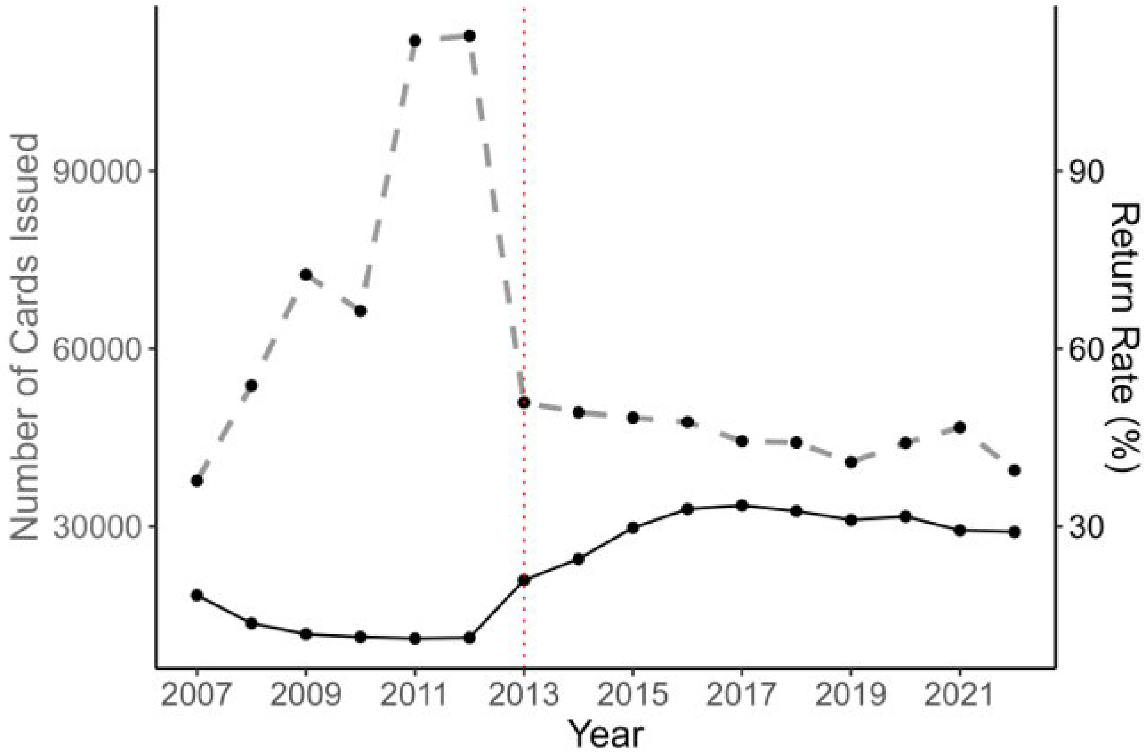

Figure 2. Sturgeon report card return sales and return rates, 2007–2022. The gray hashed line indicates number of cards issued, and dark line is the number of cards returned. Red line indicates when a purchase price for a sturgeon report card was introduced.

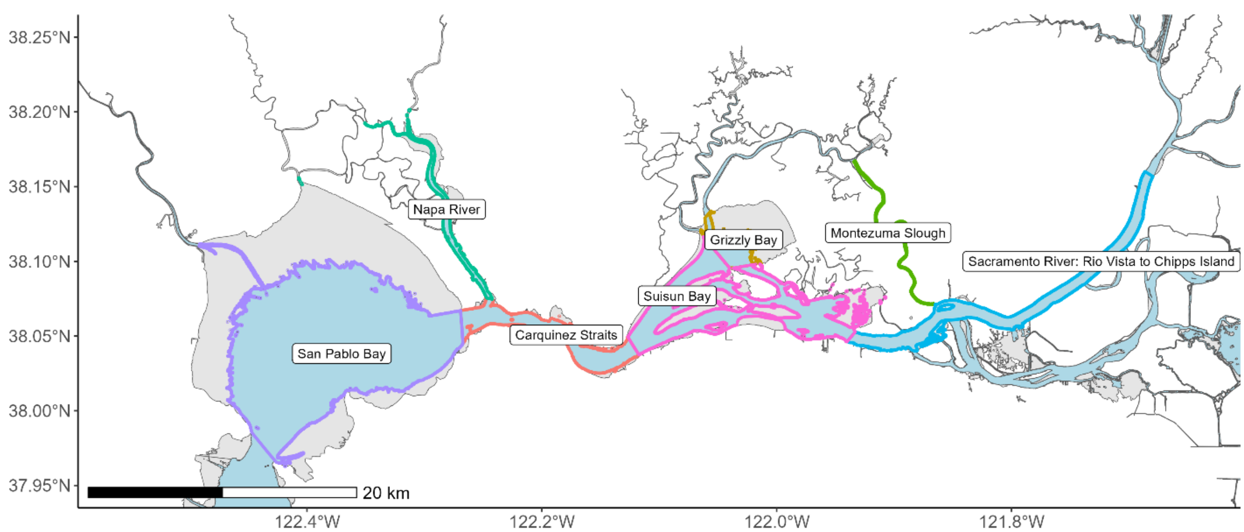

Figure 3. Map of the zones covered by the White Sturgeon mark recapture study.

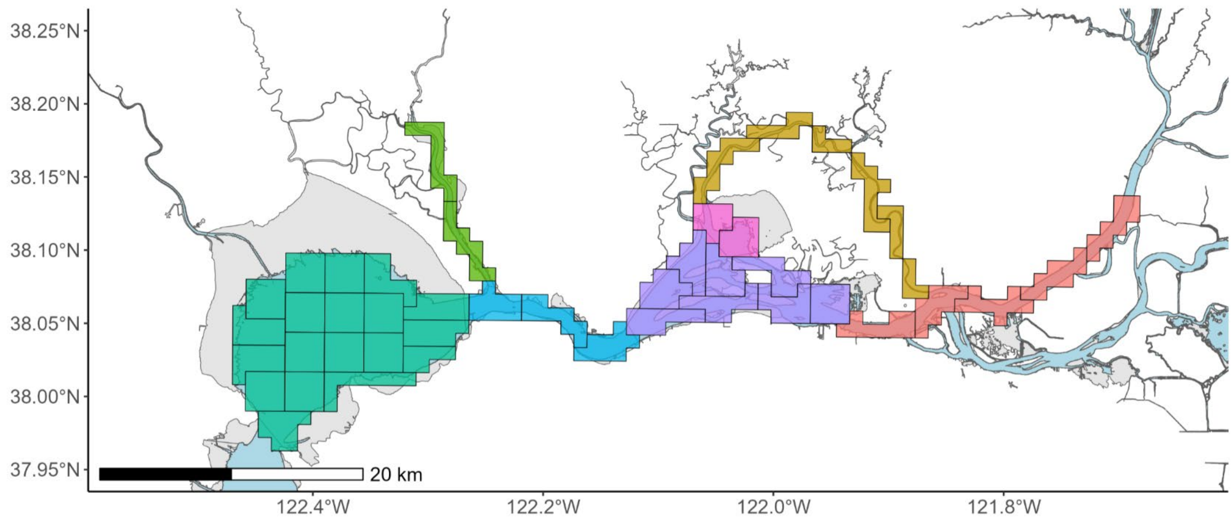

Figure 4. Map of 9 km[2] units within each survey zone. These units are used to determine the random sampling selection by the Generalized Random Tessellation Stratified method.

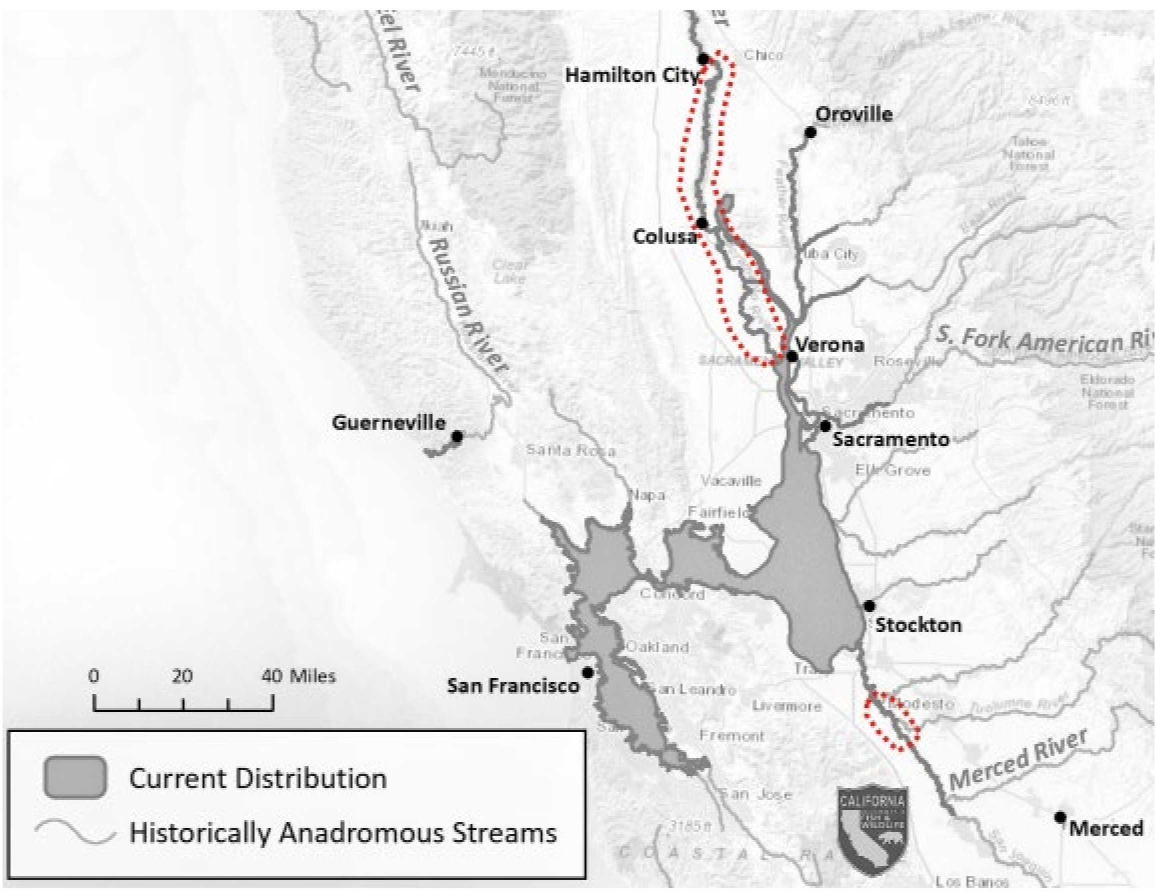

Figure 5. Proposed survey extents (red dotted lines) of the White Sturgeon spawning study in the Sacramento and San Joaquin rivers.