White Sturgeon, *Acipenser transmontanus*
Enhanced Status Report

White Sturgeon, *Acipenser transmontanus*. (Photo Credit: CDFW).

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Enhanced Status Reports

The Marine Life Management Act (MLMA) is California's primary fisheries law. It requires the California Department of Fish and Wildlife (Department) to regularly report to the California Fish and Game Commission (Commission) on the status of fisheries managed by the state. The 2018 Master Plan for Fisheries expanded on this general requirement by providing an outline for Enhanced Status Reports (ESRs) that is based on the MLMA's required contents for Fishery Management Plans (FMPs). The goal of ESRs is to provide an overview of the species, fishery, current management and monitoring efforts, and future management needs, and provide transparency around data and information that is unavailable or unknown. ESRs can help to guide Department efforts and focus future partnerships and research efforts to address information gaps and needs to more directly inform management. It is also anticipated that some ESRs will be foundations for future FMPs by providing background information and focusing analyses and stakeholder discussions on the most relevant issues.

Note that in order to describe management measures in clear terms, ESRs contain summaries of regulatory and statutory language. To ensure full compliance with all applicable laws and regulations, please refer directly to the relevant sections of the Fish and Game Code and/or Title 14 of the California Code of Regulations.

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List of Acronyms

CCR	California Code of Regulations
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
CPFV	Commercial Passenger Fishing Vessel
CPUE	Catch Per Unit Effort
DPS	Southern Distinct Population Segment
EFI	Essential Fishery Information
ESR	Enhanced Status Report
ESA	Endangered Species Act
FGC	Fish and Game Code
FL	Fork Length
FMP	Fishery Management Plan
MLMA	Marine Life Management Act
MPA	Marine Protected Area
NMFS	National Marine Fisheries Service
PSMFC	Pacific States Marine Fisheries Commission
TL	Total Length
YOY	Young of the Year

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Fishery-at-a-Glance: White Sturgeon

Scientific Name: *Acipenser transmontanus*

Range: In saltwater, White Sturgeon range from Ensenada, Mexico northward to the Gulf of Alaska, but tend to spend much of their time in freshwater and estuarine habitats in a few large river systems within their range.

Habitat: White Sturgeon primarily inhabit estuaries of large rivers and move into freshwater to spawn; less commonly some move to nearshore marine waters.

Size (length and weight): White Sturgeon can grow to be greater than 6 meters (20 feet) long and 630 kilograms (1,389 pounds).

Life span: The maximum age is unknown, but White Sturgeon may live to be greater than 100 years old.

Reproduction: White Sturgeon move upstream to lay their eggs in coarse substrates, and reproduction only occurs in large river systems such as the Columbia and Sacramento rivers. In California, spawning also occurs less commonly in the San Joaquin River, and possibly the Klamath River. Females spawn every 2 to 5 years after reaching 12 to 16 years old, while males spawn every 1 to 2 years after reaching 10 to 12 years old. In the Sacramento and San Joaquin river systems, spawning success appears related to high outflows during spring.

Prey: Young White Sturgeon feed on small crustaceans and aquatic insects. Diet broadens with growth to include a variety of bottom dwelling invertebrates, including primarily clams, crabs and shrimps, but also fish and fish eggs in certain circumstances (i.e., Eulachon, sculpins, lamprey, and spawning Pacific Herring).

Predators: Sculpins, Walleye, Smallmouth Bass and Chinook Salmon are known to prey on eggs and juvenile White Sturgeon less than 1 year old. Sea Lions and some shark species have been observed to prey upon older juvenile and adult White Sturgeon. The armored bony scutes along the body of juveniles and adults probably reduce predation relative to earlier life stages. Anglers likely pose the greatest threat to adult fish.

Fishery: The White Sturgeon fishery takes place in the San Francisco Estuary, but there has been no commercial fishery since 1917. A valuable recreational fishery began again in 1954 after a hiatus since 1917 to rebuild the stock. The recreational fishery supports a modest commercial passenger fishing vessel fleet, but most fishing occurs on private boats.

Area fished: The White Sturgeon recreational fishery focuses on the upper San Francisco Estuary (San Pablo and Suisun bays), the Sacramento-San Joaquin Delta and the Sacramento River. The Klamath River is closed to recreational sturgeon fishing.

Fishing season: In the San Francisco Estuary and the Sacramento and San Joaquin river systems, fishing for White Sturgeon is allowed year-round with some exceptions, including some closures in freshwater reaches to protect spawning fish and a closure from January 1 through March 15 in San Francisco Bay.

Fishing gear: Hook and line gear with a single barbless hook is used to fish for White Sturgeon.

Market(s): White Sturgeon is prized for its caviar. Some is illegally harvested and marketed from wild fish, whereas legal production and sales of caviar (and meat) from cultured White Sturgeon is now prevalent on the internet. In the San Francisco Estuary, the commercial fishery for White Sturgeon closed permanently in 1917, but thrived from the 1860s into the early 1890s before declining.

Current stock status: In the San Francisco Estuary over the period 2007 to 2018, White Sturgeon abundance appears generally low and possibly declining.

Management: The White Sturgeon sport fishery in California is managed to avoid over-harvest by establishment of minimum and maximum size limits (40 to 60 inches Fork Length may be retained) and bag limits of one fish per day and three fish per year, statewide. Anglers must report White Sturgeon catch and harvest, among other data, on their Sturgeon Fishing report card and return the card to the Department at the end of the year.

1. The Species

1.1. Natural History

1.1.1. Species Description

The White Sturgeon (*Acipenser transmontanus*) is the largest freshwater fish in North America, weighing up to 630 kilograms (kg) (1,389 pounds (lb)) and measuring up to 6 meters (m) (20 feet (ft)) (Richardson 1836). They are among the largest and evolutionarily oldest groups of bony fishes in the world (Moyle 2002). Adults are distinguished by blunt, rounded snouts, possessing four barbels (whisker-like appendages) in a row closer to the end of the snout than the mouth, a row of 38 to 48 mid-lateral plates, or scutes, and a heterocercal tail, in which the vertebral column extends into the upper lobe of the caudal fin and this upper lobe extends farther than the lower lobe (Miller and Lea 1972). With a sub-terminal mouth (defined as a downward-oriented mouth behind an extended rostrum) and no teeth, White Sturgeon rely on their large, highly protruding lips to extend and create suction to draw in prey. These features make White Sturgeon well adapted for feeding on bottom dwelling organisms.

Figure 1-1. White Sturgeon in profile showing distinguishing characteristics: a) barbels closer to tip of snout than to mouth; b) sub-terminal mouth; c) 38 to 48 mid-lateral scutes; and d) an asymmetrical or heterocercal tail (Photo Credit: Harry Morse, CDFW).

1.1.2. Range, Distribution, and Movement

In marine waters, White Sturgeon range from Ensenada, Mexico, north to the Aleutian Islands in the western Gulf of Alaska (Miller and Lea 1972; PSMFC 1992; Moyle 2002; Hildebrand et al. 2016) (Figure 1-2). Although the range of the species in the marine environment is broad, in practice White Sturgeon appear to make only limited, if any, movements into marine waters; most remain in the lower reaches of their natal rivers and this is the case for most adult White Sturgeon from the Sacramento-San Joaquin river system (see summary in Hildebrand et al. 2016). Most spend the majority of their lives moving between freshwater and estuarine habitats. Conversely, at least a few individuals have exhibited long-range marine movements between river basins (i.e., Welch et al. 2006) and shorter dispersals to marine habitats in some proximity to their natal rivers (Hildebrand et al. 2016 and references therein).

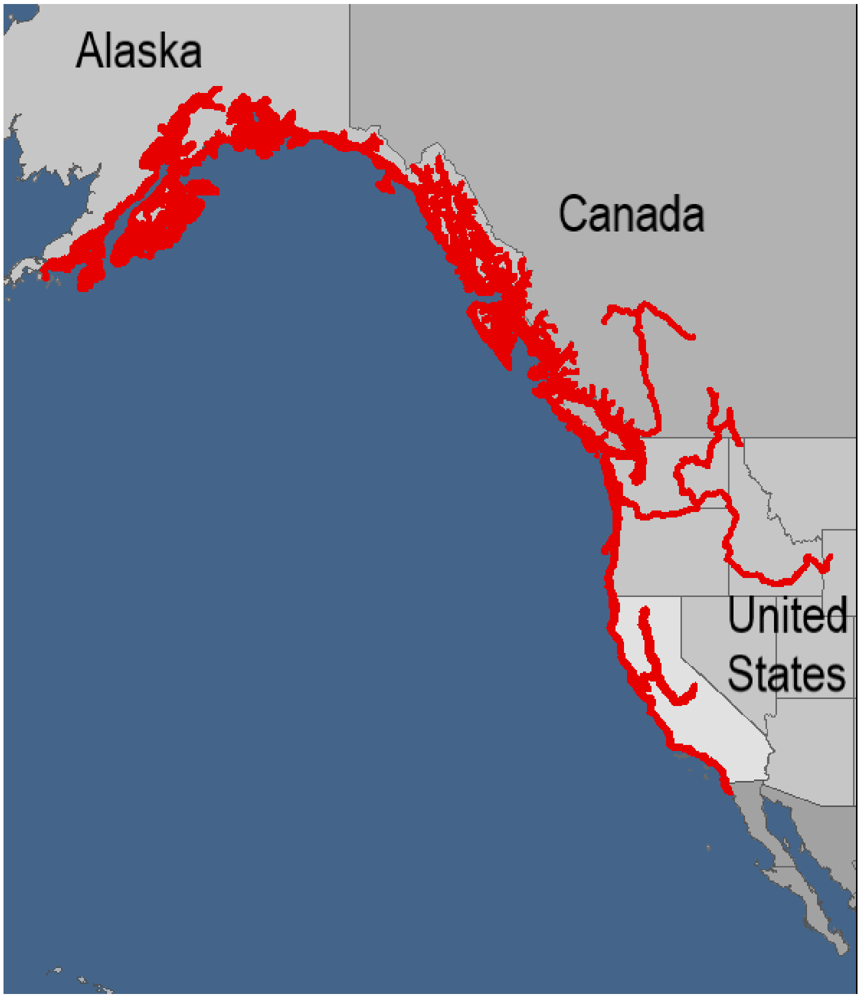

Figure 1-2. Range of White Sturgeon.

Currently, reproductive populations of White Sturgeon are known only from the Sacramento-San Joaquin river system, the Columbia River system and the Fraser River in British Columbia, and it remains unclear whether fish in the Klamath River reproduce there (Hildebrand et al. 2016). Individuals inhabiting the middle and upper sections of the Columbia and Fraser river basins complete their life cycle entirely in freshwater, whereas sturgeon in the Sacramento-San Joaquin river basins, and at least some individuals in the lower sections of the Columbia and Fraser river basins spend much of their juvenile period and subsequent non-spawning periods in brackish water in estuaries (Hildebrand et al. 2016). Only small portions of the lower Fraser River and lower Columbia River populations show evidence of movement into the marine environment (Veinott et al. 1999), and at least for the Columbia River population, movement into the marine environment appeared to be localized (DeVore et al. 1999).

In the Sacramento River, early life stages of White Sturgeon undergo two periods of dispersal; the first as newly hatched yolk-sac larvae, and the second as early juveniles. After hatching, newly mobile, non-feeding White Sturgeon yolk-sac larvae spend a brief period of low intensity downstream dispersal during which they swim near the bottom only during low light periods (Kynard and Parker 2005). This weak dispersal pattern is different from the more active dispersal displayed by other species of sturgeon, and may provide protection from predation and reduce densities prior to first feeding (Kynard and Parker 2005). Early juveniles begin a more active downstream migration that disperses them throughout the lower river and Delta (Kynard and Parker 2005). Age 0 juveniles develop tolerance for brackish water (McEnroe and Cech 1985), allowing them to exploit brackish habitats during their first summer.

Movements of White Sturgeon in the San Francisco Estuary appear relatively complex. Adults forage in San Francisco, San Pablo and Suisun bays, shifting among bays with annual and seasonal changes in salinity. Based on tag returns from 1974 to 1988, Kohlhorst et al. (1991) found that most White Sturgeon remain year-round in the estuary and tributary rivers, and are common in the brackish waters of San Pablo and Suisun bays. Fish move up- or downstream in response to salinity changes (Kohlhorst et al. 1991). Reproductive adults, which constitute a small fraction of the total population, move upstream in the Sacramento River and, to a lesser extent, the San Joaquin River in late winter and spring to spawn. Kohlhorst et al. (1991) noted that, while rare, White Sturgeon tagged in the San Francisco Estuary system have been recovered in rivers in Oregon and Washington, suggesting occasional marine migrations of long distances.

1.1.3. Reproduction, Fecundity, and Spawning Season

All White Sturgeon spawning takes place within freshwater in three large river systems in the western portion of North America. Spawning season varies by latitude and occurs between February and August range-wide. In the Sacramento-San Joaquin river system, spawning occurs between February and June, with a peak in April at water temperatures 14 to 15 °C (57 to 59 °F) (Kohlhorst 1976), and with most spawning occurring in the Sacramento River (Jackson et al. 2016). Spawning occurs April through July at 10 to 18 °C (50 to 64 °F) in the lower Columbia River (Parsley et al. 1993), and in July through August at 13 to 19 °C (55 to 66 °F) in the lower Fraser River (Perrin et al. 2003).

White Sturgeon spawn multiple times in their life, but not every year for females. Although female White Sturgeon are physiologically capable of spawning every 2 years in captivity, spawning intervals of 2 to 5 years have been estimated among wild females (Chapman et al. 1996; Doroshov et al. 1997; Hildebrand et al. 2016). Similarly, males can spawn annually in captivity (Doroshov et al. 1997), but appear to do so every 1 to 2 years in the wild (Chapman et al. 1996). Once mature (see section 1.1.6), White Sturgeon migrate to riverine habitats as day length and water temperatures increase in the early spring (Doroshov et al. 1997). Spawning has been documented as occurring between 8 and 20 °C (46 to 68 °F) (Hildebrand et al. 2016).

White Sturgeon fecundity increases with body size. It has been estimated that a 100 centimeter (cm) (39 inches (in)) Fork Length (FL) female produces 47,000 eggs whereas a 150 cm (59 in) FL female produces 210,000 eggs (Beamesderfer et al. 1989), though measurements of fecundity from the lower Columbia River ranged as high as about 700,000 eggs in very large females (DeVore et al. 1995; Wydoski and Whitney 2003).

White Sturgeon broadcast-spawn adhesive eggs over coarse substrates and provide no parental care. Parsley et al. (1993) observed spawning in swift flowing freshwater of 0.8 to 2.8 m/second (2.6 to 9.2 ft/second) at one location with a depth of approximately 7 m (23 ft). The outer coat of eggs is adhesive, which serves to adhere the egg to the substrate and protect it from fungal disease before fertilization occurs (Conte et al. 1988). The concentration of sperm in the surrounding area is lower than that of nest spawners; the sperm are only motile for up to 3 minutes, and after 5 minutes motility ceases (Conte et al.1988). Fertilization occurs when the egg and sperm are in contact in water (Conte et al. 1988). Newly spawned eggs were collected at depths of 4.0 to 24.0 m (13.1 to 78.7 ft) (Parsley et al. 1993).

1.1.4. Natural Mortality

Determining the natural mortality (M) of marine species is important for understanding the health and productivity of their stocks. Natural mortality describes all causes of death not attributable to fishing such as old age, disease, predation or environmental stress. Natural mortality is generally expressed as the percentage of the population dying in a year. Fish with high natural mortality rates must replace themselves more often and thus tend to be more productive. Natural mortality along with fishing mortality result in the total mortality operating on the fish stock.

Young White Sturgeon (15 to 100 cm (6 to 40 in) Total Length (TL)) in the lower Fraser River experienced 17% annual natural mortality (Bennett et al. 2005). Adult White Sturgeon experienced 4 to 10% natural mortality in the lower Columbia River

(Beamesderfer et al.1995; DeVore et al. 1995); 3% in the upper Columbia River (Irvine et al. 2007); and 4 to 9% in the Fraser River (Semakula and Larkin 1968; Walters et al. 2005). Adults are thought to experience low predation due to their large size and armored bony scutes along their body, and this may contribute to long lifespans.

While the maximum age of White Sturgeon remains unknown, Rien and Beamesderfer (1994) reviewed both the accuracy and precision of the estimates of Columbia River White Sturgeon ages from pectoral fin rays and observed a maximum age of 104 years. That study found that only 37% of the samples had the same age assigned by different readers, displaying the lack of appropriate methods to assign age to this species in comparison to others (Rien and Beamesderfer 1994). Inaccurate age estimation can result in other estimation errors such as sustainable exploitation rates, growth, and mortality which restrict data interpretation for potential management regimes (Rien and Beamesderfer 1994).

Blackburn (2018) estimated White Sturgeon survival rate (using 2014 to 2016 mark-recapture data) at 0.81 (0.801 to 0.825 95% confidence interval) for ages 3 to 19. For the same age range, instantaneous mortality was 0.21 (0.12 to 0.29 95% confidence interval).

1.1.5. Individual Growth

Individual growth of marine species can be quite variable, not only among different species but also within the same species. Growth is often very rapid in young fish, but slows with maturity and again as adults approach their maximum size. The von Bertalanffy Growth Model has been used to model White Sturgeon growth (Kohlhorst et al. 1980; Blackburn 2018; Blackburn et al. 2019).

Juvenile White Sturgeon grow rapidly in culture at 16 °C (61 °F): body weights double every 2 to 3 weeks during their first 4 months of life (Brannon et al. 1984). Although they are likely to grow less rapidly in the wild, juvenile White Sturgeon in the Sacramento River reach 43 to 45 cm (17 to 18 in) TL at the end of their first year and then grow at a rate of 2.0 to 6.0 cm (0.8 to 2.4 in) per year after reaching 102 cm (40 in) TL (Brennan and Cailliet 1989; Hildebrand et al. 2016). Juveniles on average achieve 100 cm FL by age 9 and reach the 102 cm FL lower boundary of the harvestable slot limit that same age (Blackburn 2018; Blackburn et al. 2019). More specifically, a few juveniles enter the harvestable range (102 to 152 mm FL= 114 to 170 mm TL) by age 8 but virtually all have entered by age 13 (DuBois et al. 2010).

1.1.6. Size and Age at Maturity

White Sturgeon are late maturing, and both size and age at maturity vary across the species' range (see Hildebrand et al. 2016). In the Sacramento-San Joaquin river system, a small fraction of males sampled reached maturity between 100 and 105 cm (39 to 41 in) FL; and the first mature female observed was 104 (41 in) FL, but <10 percent of the females observed were mature prior to 135 cm (53 in); beginning about 135 cm FL (≥53 in) the fraction of mature females increased to 20 percent and further increased with increasing length (Chapman et al. 1996). Males of 100 and 105 cm (39 to 41 in) FL would have averaged about 9 to 10 years of age, respectively; a female at 104 cm (41 in) would have been 9 to 10 years old as well and those at 135 cm (53 in) would have been about 14 years old based on back calculated length at age from Blackburn (2018). Blackburn (2018) estimated FL at age from recent sampling data (2014 to 2016) and provides evidence that White Sturgeon length at age is greater based on this recent data than for data from the 1970s. Age of maturity is much reduced in captivity, where males and females mature at an average age of 4 and 8 years, respectively (Doroshov et al. 1997).

1.2. Population Status and Dynamics

Population estimates for White Sturgeon in the San Francisco Estuary have been conducted periodically and can fluctuate dramatically. Recent estimates suggest that the San Francisco Estuary population has declined in recent years. White Sturgeon are long-lived and exhibit highly variable recruitment. Most White Sturgeon in California recruit to the fishery at about 9 or 10 years old and mature around age 15. Their late maturity, combined with the fact that females spawn every 2 to 5 years, means that productivity is likely to be low. In addition, recruitment success is correlated to high Delta outflow, and thus large year-classes only occur in in wet years (Stevens and Miller 1970; Kohlhorst et al. 1991; CDFG 2008, Fish 2010), which have become more sporadic recently. Between 2000 and 2018, only three years have been classified as “wet” and produced White Sturgeon year-classes: 2006, 2011 and 2017, as compared to 1980 to 1989 when there were four wet years, and 1990 to 1999 which experienced five wet years (Figure 1.3. http://cdec.water.ca.gov/reportapp/javareports?name=wsihist). These factors combine to make White Sturgeon highly vulnerable to overfishing.

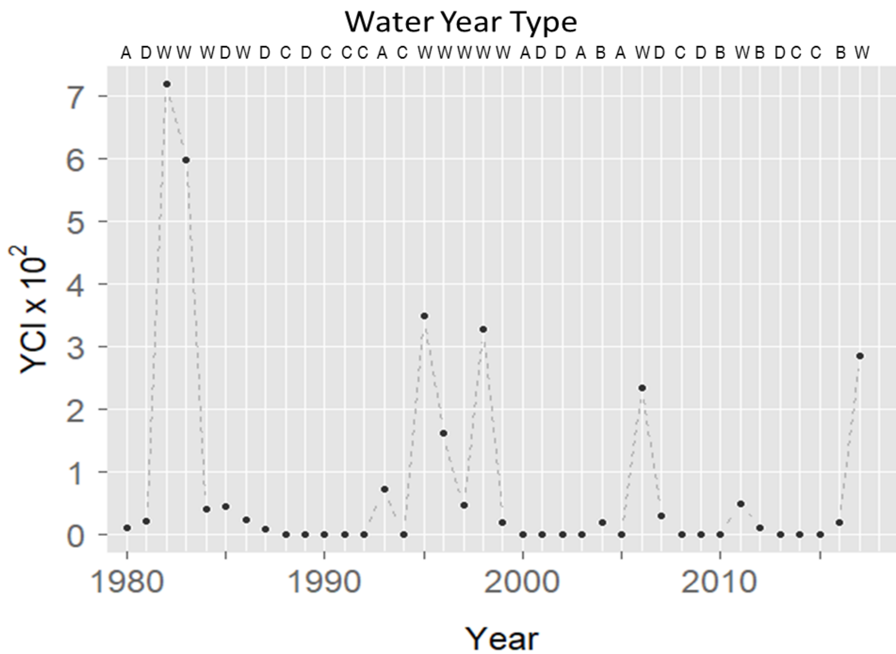

Figure 1-3. Sacramento Valley water-year type (top x-axis) versus annual age 0 White Sturgeon abundance index (year class index (YCI); data accessed 2019 from CDFW San Francisco Bay Study sampling; YCI calculated per methods described in Fish 2010), 1980 to 2018 (bottom x-axis; no sampling in 2018; data accessed 2019 from San Francisco Bay Study otter trawl data). Water year types: W = wet; A = above normal; B = below normal; D = dry; C = critical; where water year type is a rating for the water available to flow through the Sacramento River system (data accessed 2019 from http://cdec.water.ca.gov/reportapp/javareports?name=wsihist).

1.2.1. Abundance Estimates

The abundance of White Sturgeon in the San Francisco Estuary has been estimated periodically since the 1950s using a variety of mark-recapture methodologies and assumptions (Kohlhorst et al. 1991). Beginning in 2007, in response to changes in the legal harvestable size-range, abundance has been estimated by dividing the number of fish reported harvested by harvest rate (number of tags returned by anglers divided by number of tagged fish released by the Department). This method requires less data, can be done within a year of collecting data, and it is thought to be as accurate as previous estimates (DuBois and Gingras 2011). Abundance also has been indexed using calculations based on catch per net-hour during tagging (Kohlhorst 1980). In each case, the calculation specifically estimated the number of legal-sized fish (i.e., fish in a size range that allowed legal harvest), which has varied through time (section 3.1).

Absolute abundance estimates of legal-sized White Sturgeon have fluctuated widely, both over the long term and from year to year (e.g. about 51,500 in 1993 and 208,000 in 1994, though note that the large confidence interval for 1994, includes zero) (Figure 1-4). Absolute abundances calculated from harvest and harvest rates beginning in 2007 exhibited more consistent year-to-year values, but generally remained low (Figure 1-4). This harvest-based method provided lower abundance estimates compared to traditional Peterson mark-recapture estimates during the period from 2007 through 2009, and slightly higher estimates in 2012 and 2013, but still depict an oscillating pattern of decline.

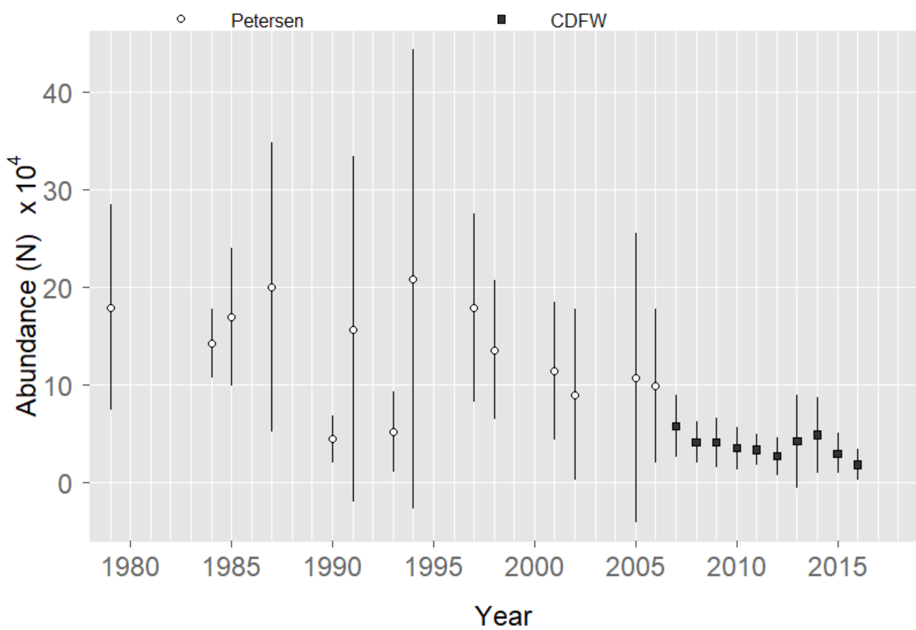

Figure 1-4. Absolute abundance estimates (±95% Confidence Interval) of legal-sized White Sturgeon in the San Francisco Estuary, based on Peterson mark-recapture methodology, sporadically 1979 to 2006 (white circles), and estimated from harvest rate (from mark-recapture) and angler harvest (tag returns) annually 2007 to 2016 (black squares). Data source CDFW Sturgeon tagging field sampling (mark-recapture) and Sturgeon Report Cards, accessed 2019.

Catch Per Unit Effort (CPUE) data from trammel net fishing used to tag White Sturgeon also depicts an oscillating decline, where periodic peaks in the 2000s are much lower than those in the 1990s and 1980s (Figure 1-5).

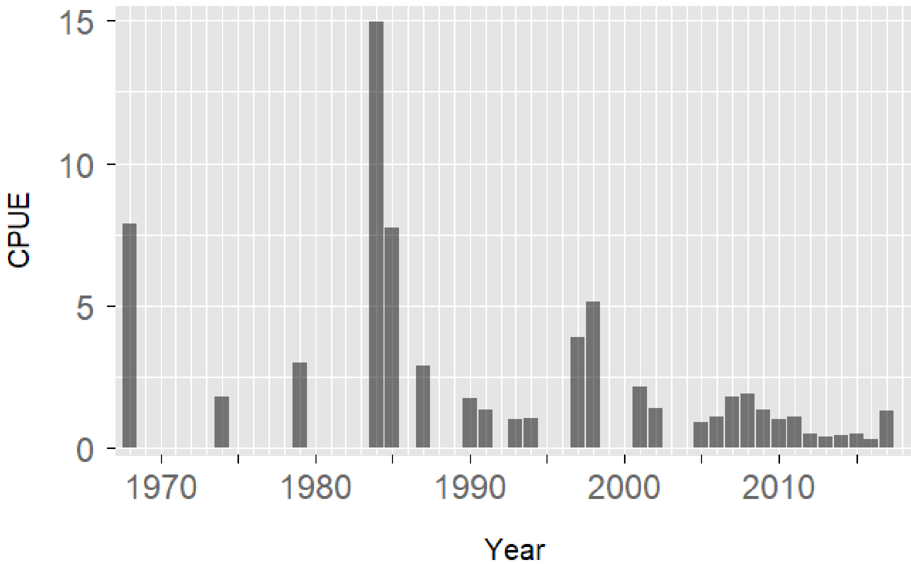

Figure 1-5. CPUE of legal-sized White Sturgeon caught in trammel net fishing in the San Francisco Estuary, 1968 to 2018 (no sampling occurred in 2018). A unit of effort is 100 net-fathom hours of fishing time. Data source CDFW Sturgeon tagging field sampling (mark-recapture), accessed 2019.

1.2.2. Age Structure of the Population

The age structure of the San Francisco Estuary White Sturgeon population has been determined periodically from reading annual rings of pectoral fin rays (Kohlhorst et al. 1980; DuBois et al. 2010a). However, because this method of aging is resource intensive, existing historical age and length data (1973 to 1976) have been used to create an age-length key (DuBois et al. 2010a), which in turn has been used to predict ages based on length for un-aged fish (DuBois et al. 2010a). More recent age and length data (2014 to 2017) shows fish are currently slightly larger at age than in the 1970s, and also that the dominant mode in the age distribution centered around age 8 years (Blackburn 2018; Blackburn et al. 2019) and is about to enter the harvestable range of the sport fishery. Further, Blackburn (2018) found very few fish over age 20 and only a maximum age of 29.

1.2.3. Size Structure of the Population

The size structure of the population, particularly as it relates to the size range for harvestable fish, is another important metric for management of the White Sturgeon population. Length data from the sturgeon report card provides a relatively detailed view of the annual size distribution of harvestable fish (Figure 1-6). The relative frequency of sizes can be used to detect entry of strong year-classes into the harvestable size range (e.g., 2015 in Figure 1-6) and to follow progress of a strong year-class through the range (e.g., 2007 to 2013 in Figure 1-6). In conjunction with the knowledge that entry into the harvestable size range of 40.0 to 60.0 in (1.0 to 1.5

m) FL begins at age 8 and entry is not completed until age 13 due to variation in growth (Dubois et al. 2010a), White Sturgeon are predicted to begin to out-grow the harvestable size range beginning at age 16, but do not complete the process by age 21, the limit of the historical data used to predict length at age (Dubois et al. 2010). From this information, the relatively large number of fish recruiting to harvestable size in 2015 (Figure 1-6) likely derived from the 2006 year-class.

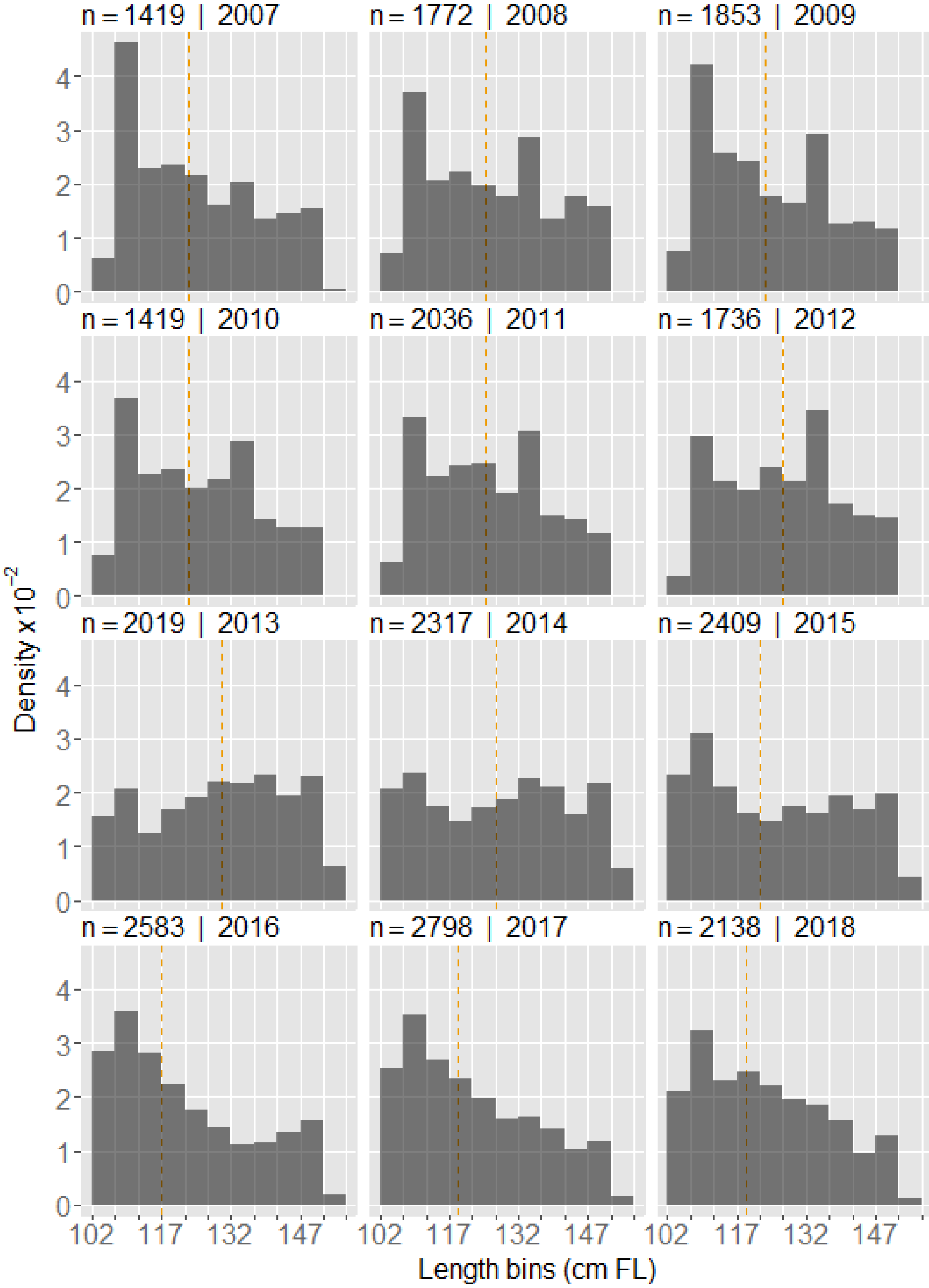

Figure 1-6. White Sturgeon annual length frequency as a fraction of total annual catch (year and catch listed above graphic) based on legal-sized fish reported as harvested annually from 2007 through 2018 (CDFW White Sturgeon report card data, accessed April 2019). Vertical dashed line indicates median length.

1.3. Habitat

Reproductive White Sturgeon are believed to return to particular river reaches and then select specific areas for egg deposition based on water velocity, turbulence, depth, and bottom composition (Hildebrand et al. 2016). Spawning takes place in fast-flowing waters over coarse bottom materials (though occasionally finer particles such as sand or clay are present) located in main river channels and in some cases large side channels (Parsley et al. 1993; Schaffter 1997; Perrin et al. 2003). Fast, turbulent water disperses eggs across the bottom, possibly reducing density-dependent mortality (Hildebrand et al. 2016). Recently hatched embryos appear to have highest rates of survival in the interstitial spaces among coarse bottom particles (Hildebrand et al. 2016).

Feeding larvae and early juveniles seek habitats with low water velocity in main channel reaches, side channels and sloughs. In the lower Fraser River, juveniles were most frequently caught during summer months in tidal sloughs or channels (currents varied in speed and direction), 5.0 m (16.4 ft) or deeper, water temperatures between 15 to 20 degree Celsius (°C) (59 to 68 degrees Fahrenheit (°F)), with mostly fine sediments and highly variable turbidities (1.5 to 86.0 Nephelometric Turbidity Unit) (Bennett et al. 2005).

In the San Francisco Estuary, older juveniles and adults inhabit estuarine habitats ranging from the Sacramento-San Joaquin Delta downstream into marine waters of central San Francisco and south San Francisco bays, with the greatest numbers inhabiting Suisun and San Pablo bays (Kohlhorst et al. 1991; DuBois et al. 2010a).

1.4. Ecosystem Role

Within California, adult White Sturgeon are high-level predators in the benthic community of the San Francisco Estuary. They are opportunistic predators of benthic fish and invertebrates.

1.4.1. Associated Species

White Sturgeon associate with the benthic invertebrate and fish communities in the lower and mid-reaches of the Sacramento and San Joaquin river systems, the Sacramento-San Joaquin Delta, Suisun Bay and Marsh, San Pablo Bay and central and south San Francisco bays. Given the many areas in which White Sturgeon live, the number of associated species is extensive (Baxter et al. 1999; Moyle 2002). Bycatch in research sampling in areas where White Sturgeon live provide a view of the kinds of species associated with White Sturgeon, and these are listed in Tables 1-1 and 1-2 (DuBois et al. 2010b; DuBois et al. 2011). Setline sampling for juvenile White Sturgeon in the San Francisco Estuary produced a wide array of freshwater, estuarine and marine fishes (Table 1-1, DuBois et al. 2010a). Similarly, bycatch in the trammel net survey included species collected with large juveniles and adults (Table 1-2, DuBois et al. 2010b; DuBois et al. 2011).

Table 1-1. Species co-occurring with juvenile White Sturgeon based on setline sampling in the San Francisco Estuary, 1995 to 2002 (DuBois et al. 2010a).

Common name	Species name
Bat Ray	*Myliobatis californica*
Brown Smoothhound	*Mustelus henlei*
Channel Catfish	*Ictalurus punctatus*
Green Sturgeon	*Acipenser medirostris*
Leopard Shark	*Triakis semifasciata*
Sacramento Blackfish	*Orthodon microlepidotus*
Sacramento Pikeminnow	*Ptychocheilus grandis*
Sevengill Shark	*Notorynchus cepedianus*
Splittail	*Pogonichthys macrolepidotus*
Spiny Dogfish	*Squalus acanthias*
Staghorn Sculpin	*Leptocottus armatus*
Starry Flounder	*Platichthys stellatus*
Striped Bass	*Morone saxatilis*
Thresher Shark	*Alopias vulpinus*
White Catfish	*Ameiurus catus*
White Croaker	*Genyonemus lineatus*

Table 1-2. Species co-occurring with adult White Sturgeon based on trammel net sampling in the San Francisco Estuary, 2010 to 2011 (DuBois et al. 2010b; DuBois et al. 2011).

Common name	Species name
Bat Ray	*Myliobatis californica*
Brown Smoothhound	*Mustelus henlei*
California Halibut	*Paralichthys californicus*
Chinook Salmon	*Oncorhynchus tshawytscha*
Diamond Turbot	*Hypsopsetta guttulata*
Green Sturgeon	*Acipenser medirostris*
Leopard Shark	*Triakis semifasciata*
Seven-gill Shark	*Notorynchus cepedianus*
Starry Flounder	*Platichthys stellatus*
Striped Bass	*Morone saxatilis*
White Croaker	*Genyonemus lineatus*

1.4.2. Predator-prey Interactions

White Sturgeon are well adapted to preying on bottom-dwelling organisms, even in areas of high turbidity and low visibility. The species is able to use smell and electroreception, as well as taste and touch associated with the row of sensitive barbels on the underside of their rostrums. Once prey is detected, sturgeon swallow it whole using their sub-terminal mouth with long, extensible “lips”. Young White Sturgeon feed on small crustaceans (e.g. amphipods and mysid shrimp) and aquatic insects (Radtke 1966). Their diet broadens as they grow to include a variety of bottom dwelling invertebrates, primarily clams, crabs and shrimps, but also fish and fish eggs in certain circumstances (Radtke 1966). After the invasion of the Over-bite Clam (*Potamocorbula amurensis*) in the 1980s, the clam itself and fish have become larger components of the White Sturgeon diet in the San Francisco Estuary (Zeug et al. 2014).

White Sturgeon eggs are vulnerable to benthic feeding organisms. Known predators of White Sturgeon eggs include Northern Pikeminnow (*Ptychocheilus oregonensis*), Largescale Sucker (*Catostomus macrocheilus*), Prickly Sculpin (*Cottus asper*) and Common Carp (*Cyprinus carpio*) (Miller and Beckman 1996). In lab experiments, Prickly Sculpin predation on White Sturgeon yolk sac larvae increased with reduced turbidity levels and significantly decreased at the lowest light levels with the presence of cover. This was especially true for small larvae that were best able to take advantage of the cover (Gadomski and Parsley 2005). In the San Francisco Estuary, young White Sturgeon are occasionally preyed upon by Striped Bass (Grossman 2016). While they have few predators as adults other than humans, they are occasionally preyed upon by large sharks, sea lions and other marine mammals.

1.5. Effects of Changing Oceanic Conditions

White Sturgeon in California are believed to occur in primarily estuarine and riverine habitats, and spend only a small proportion of their time moving outside the estuary to the open coast. However, within the estuary, certain components of the estuarine fish and invertebrate communities are strongly affected by climate driven ocean variability (i.e., currents and temperature), whereas others more strongly responded to land-based climate processes, such as precipitation and outflow (Cloern et al. 2010; Peterson and Vayssieres 2010; Feyrer et al. 2015). Such mechanisms not only influence the estuarine environment, and thus the physiology of White Sturgeon, but also the abundance and distribution of organisms forming the food base for White Sturgeon (Kimmerer 2002; Peterson and Vayssieres 2010).

White Sturgeon distribution is highly related to salinity patterns, with many fish inhabiting the brackish water of Suisun and San Pablo bays throughout the year (Kohlhorst et al. 1991). Further, these fish tend to move downstream in the winter when river flows tend to freshen Suisun Bay, and a portion move upstream into the Delta and lower Sacramento River beginning in fall and increasingly in winter, before presumably mature fish move farther into the Sacramento River in spring to spawn (Kohlhorst et al. 1991). In addition, abundance in the San Francisco Estuary is highly variable through time, and strong year-classes occur only in years when the Sacramento Valley Water Year index was rated “wet” and river flows were very high (Figure 1-3) (CDFG 2008). Changing ocean conditions will influence weather, precipitation and riverine flow and will likely affect sturgeon recruitment, particularly if years of high river runoff occur less frequently (Kohlhorst et al. 1991; Fish 2010). The frequency of wet years has declined across the decades from the 1980s through the present, leading to longer periods of little or no recruitment. This may have contributed to the declining adult abundances observed since that time (see section 1.2.1).

2. The Fishery

2.1. Location of the Fishery

The primary region targeted by the recreational White Sturgeon fishery is the San Francisco Estuary, including central San Francisco Bay, San Pablo Bay, Suisun Bay and the Sacramento-San Joaquin Delta; however, fishing also occurs in the Sacramento, American and Feather rivers (Kohlhorst et al. 1991; Titus et al. 2010). White Sturgeon are successfully harvested throughout the estuary in various depths, salinities, and locations.

2.2. Fishing Effort

2.2.1. Number of Vessels and Participants over Time

The Department tracks Commercial Passenger Fishing Vessel (CPFV) guided fishing trips through reporting (trip logs) they are obligated to complete as part of their permit to operate. From 1980 to 2018, the number of CPFVs permitted to operate in the San Francisco Estuary ranged between 9 and 33, with the maximum occurring in 2018 (CDFW unpublished). Since 2007, the Department has been able to collect data on angling effort via returned White Sturgeon report cards. Approximately 44,000 anglers purchased report cards in 2017 (Table 2-1). In 2007, possession of a report card became mandatory when fishing for White Sturgeon, and the report cards were issued for free until 2012. Beginning in 2013, payment was required for report cards (section 3.1) and the number of cards issued dropped by half, suggesting that the number of cards issued before 2013 might not have been an accurate reflection of actual participation in the fishery and instead may represent simply an intention to participate.

Table 2-1. Number of sturgeon report cards issued per year and data for angler effort and sturgeon catch (both White and Green Sturgeon) and harvest (White Sturgeon only), 2007 to 2018. Note: in years prior to 2013, report cards were free and likely do not represent actual White Sturgeon angling effort (CDFW White Sturgeon report card data, Accessed April 2019).

Year	Cards Issued	Cards returned with zero effort	Cards returned with zero catch	Returned with catch (both Green and White)
2007	37,680	NA	5,062	1,859
2008	53,777	NA	5,280	2,051
2009	72,499	NA	6,342	2,208
2010	66,357	1478	4,262	1,756
2011	112,000	4,354	5,703	2,259
2012	112,800	5,380	5,205	2,053
2013	50,915	3,129	5,212	2,299

Year	Cards Issued	Cards returned with zero effort	Cards returned with zero catch	Returned with catch (both Green and White)
2014	49,260	3,256	6,169	2,646
2015	48,337	4,421	7,044	2,908
2016	47,617	6,121	6,669	2,861
2017	44,374	4,618	7,084	2,876
2018	44,146	4,839	6,946	2,391

In 2017 approximately 1,400 anglers participated in CPFV guided trips in the San Francisco Estuary targeting White Sturgeon (Figure 2-1) (CDFW Marine Log System (MLS)).

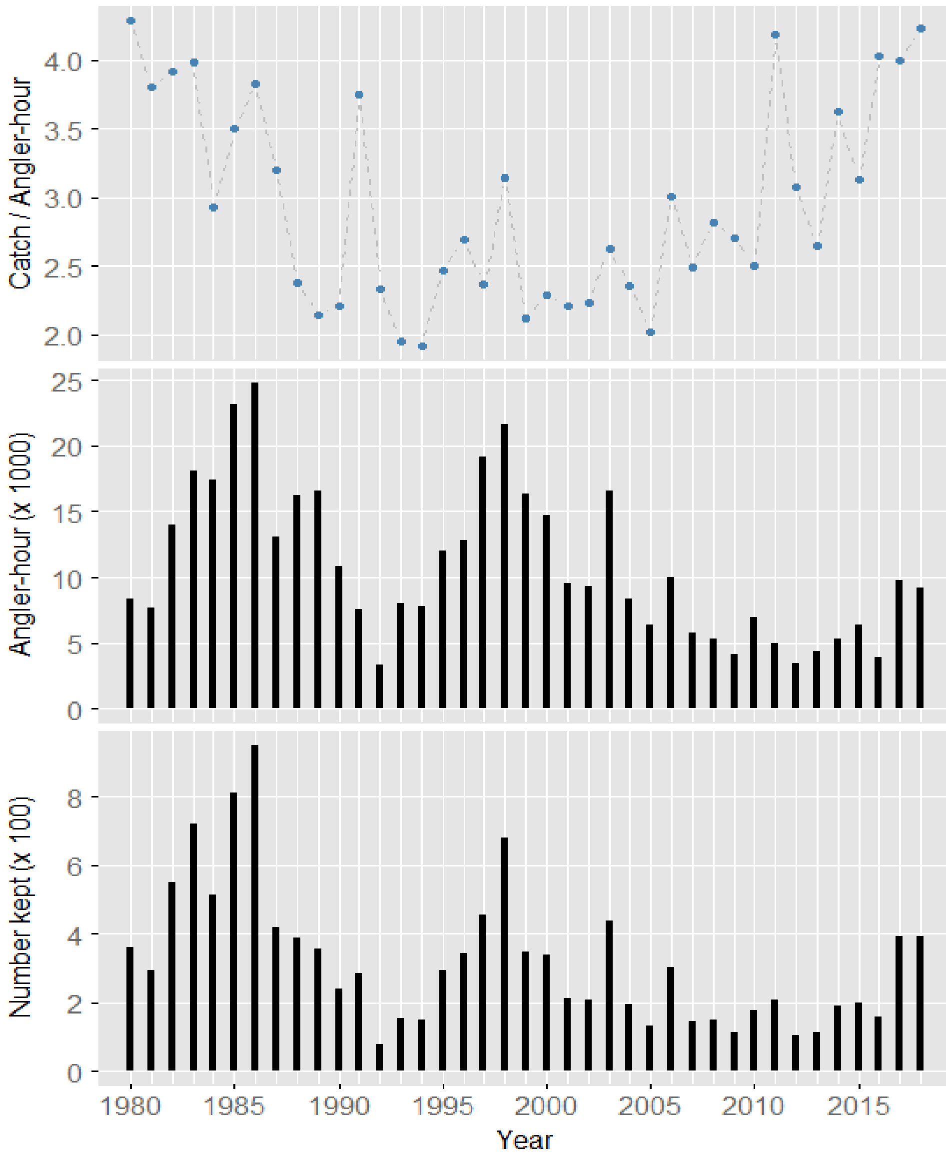

Figure 2-1. Inter-annual trends in Commercial Passenger Fishing Vessel (CPFV) angler numbers and Sturgeon harvested,1980 to 2018. Years prior to 2016 contain data for both Green and White Sturgeon, though the majority of the catch is believed to be White Sturgeon. Only trips where at least one sturgeon was kept are included (CDFW CPFV logbook data, accessed January 2019).

2.2.2. Type, Amount, and Selectivity of Gear

In California, a commercial fishery for White Sturgeon meat and caviar lasted from the 1860s to the early 1900s. Commercial fisherman commonly used gill nets, long lines, and snagging hooks to harvest White Sturgeon. Commercial fishing of White Sturgeon was permanently banned in California in 1917 (Skinner 1962; Roberts and Gingras 2010).

Recreational fishing of White Sturgeon has been allowed since its reinstatement in 1954. From 1954 through 1955 snagging White Sturgeon was legal, but was banned in 1956. Hook and line fishing, other than snagging, was unproductive after the snagging ban (Skinner 1962) until 1964 when shrimp, initially *Crangon* spp. and Asian Shrimp (*Palaemon macrodactylus*); and later burrowing shrimp (*Callianassa* spp. and *Upogebia* spp.) were first used as bait. Following this, the exploitation rate increased sharply (Kohlhorst et al. 1991). Current laws only allow single barbless hook angling as a method of take for White Sturgeon. Recreational angling for White Sturgeon is limited to a maximum of two rods per individual. As of 1990 and 2013, respectively, no gaffs or snares may be used to help land White Sturgeon (§5.80, Title 14, CCR).

Hook and line gear is largely non-selective for White Sturgeon. A broad size-range of sturgeon are caught and released by the recreational fishery. Non-mandatory measurements of released fish from the 2017 Sturgeon report cards indicated White Sturgeon ranged from about 10 to 114 in FL (25 to 290 cm), with most in the 30 to 40 in FL (76 to 102 cm) range, just less than the minimum size of legal harvest (DuBois and Danos 2018). These data indicate the potential for the fishery to negatively affect White Sturgeon for years prior to and after their time within the slot limit for legal retention and support the need for continued education on proper handling during capture and release.

2.3. Landings in the Recreational and Commercial Sectors

2.3.1. Recreational

The Department has been able to track the recreational harvest and release of White Sturgeon since the implementation of the report card program in 2007. In 2017, most catch of White Sturgeon occurred in Suisun and San Pablo bays. Anglers reported the retention of 2,755 White Sturgeon (Figure 2-2), and release of 4,817 White Sturgeon. As has been the case since 2007, less than 30% of the reporting anglers who fished for White Sturgeon were successful in 2017 (annual success range 26 to 31%) and successful anglers retained on average about one-third the annual bag limit of three White Sturgeon (Table 2-1).

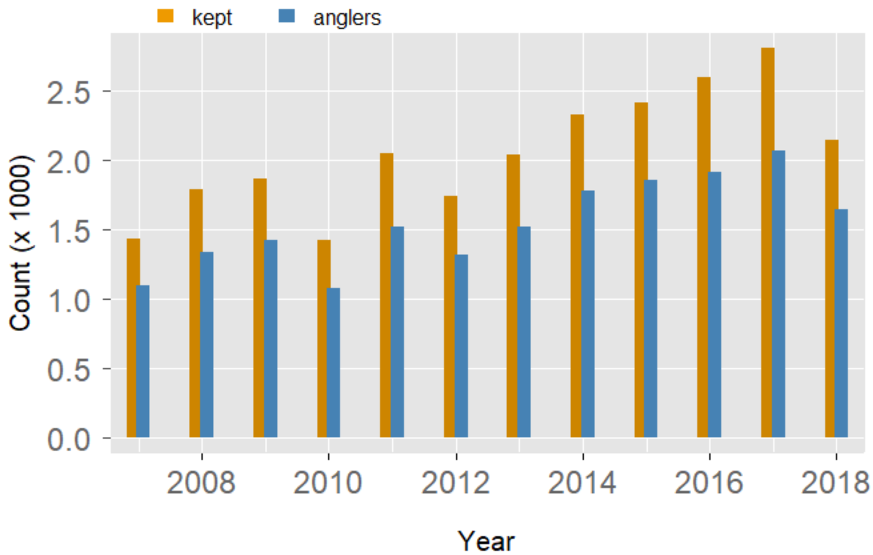

Figure 2-2. Annual counts of White Sturgeon retained (orange bars) and anglers fishing for sturgeon (blue bars) for 2007 to 2018 (CDFW White Sturgeon report card data, accessed April 2019).

2.3.2. Commercial

Commercial fishing for White Sturgeon in California has been banned since 1917.

2.4. Social and Economic Factors Related to the Fishery

Recreational fishing for White Sturgeon is often conducted via chartered boats, with many fishing guides in San Francisco and the Bay-Delta area offering sturgeon fishing trips. Information from CPFVs and Sturgeon report cards provide important data for estimating total number of White Sturgeon caught in the fishery. White Sturgeon provide a high-quality meat, and are also targeted by some anglers for their prized roe to make caviar. Poaching White Sturgeon for caviar makes up an unknown, yet potentially significant portion of the White Sturgeon total catch and led to amendments of the Fish and Game Code (FGC) circa 2007 that “substantially increased the penalty for illegal commercialization of sturgeon and made it easier to establish intent to illegally commercialize sturgeon” (Roberts and Gingras 2010).

It is unknown how much anglers targeting White Sturgeon contribute to the recreational fishing economy. Advertised rates for chartered fishing trips to catch White Sturgeon are somewhat variable by season and guide, but can range from $200 to $450 per person per day. Although the fishery is open year-round, the majority of White Sturgeon catches occur in the winter and spring, with a notable decrease in fishing success in the summer months (DuBois and Danos 2018). During the summer months, catch rate for Striped Bass, Chinook Salmon, and other common recreational targets are higher so fishermen switch to those species. Unfortunately, the winter period also coincides with the White Sturgeon spawning migration, and fishing during this time may have a greater impact on the long-term population health. Approximately 1,200 anglers participated in guided trips in 2018, indicating that the recreational White Sturgeon fishery is a modest contributor to California’s $2.9 billion annual recreational fishing industry (ASA 2019).

3. Management

3.1. Past and Current Management Measures

A commercial sturgeon fishery developed in the San Francisco Bay Estuary in the 1860s to supply the increasing demand for caviar and smoked sturgeon in the eastern United States. Records from the time do not differentiate between species, though the significant majority of the captured fish are believed to have been White Sturgeon as opposed to Green Sturgeon. The gear used in the commercial fishery included gill nets, long lines and snagging hooks. The commercial fishery peaked in 1885 when 1.65 million lb were landed (Jordan and Gilbert 1887). Heavy commercial fishing led to serious resource depletion by 1900 and the fishery for sturgeon closed in 1901. The fishery reopened in 1909; however, small catches indicated that the population was still depressed. The commercial and recreational sturgeon fisheries closed in 1917, and the commercial fishery has remained closed. The recreational fishery for sturgeon (White and Green Sturgeon combined) was reestablished in 1954 with a 40 in (100 cm) TL minimum size limit, no seasonal closure, and a one fish per day bag limit (Pycha 1956).

A tagging study conducted in 1954 showed that the sturgeon fishery is dependent upon widely spaced strong year-classes. This tagging study resulted in a recommendation for a 50.0 in (130 cm) minimum size limit for both sturgeon species to provide a buffer stock of larger fish for anglers and to insure maintenance of an adequate spawning stock (Pycha 1956). The new size limit was implemented in 1956, the same year that snagging sturgeon became illegal. Subsequently, sturgeon could only be taken by angling, which is defined as the fish voluntarily taking bait or a lure in its mouth (§5.80, Title 14, CCR). The minimum size limit was returned to 40 in (100 cm) in 1964. Concern over potential depletion of the sturgeon resource in the late 1980s prompted regulation changes starting in 1990 with the implementation of a 72.0 in (180 cm) TL maximum size limit, creating the first slot size limit regulation for a marine species in California. The slot size limit protects smaller, non-reproductive, juvenile fish as well as larger fish with the highest reproductive capacity. In 1990, the minimum size limit was increased by 2.0 in (5.1 cm) each year until 1992 when a minimum size limit of 46.0 in (120 cm) was reached (§5.80, Title 14, CCR).

In 2007, several new recreational fishing regulations were implemented for the White Sturgeon fishery to assist enforcement, and to reduce the catch and the bycatch of Green Sturgeon, which was listed as threatened under the federal Endangered Species Act (ESA). The new regulations provided for an annual limit of three White Sturgeon and a reduction in the maximum size limit to 66.0 in (168 cm) TL, added a requirement to record all catch and harvest on a report card, and added a requirement to tag all retained White Sturgeon (§5.79; 5.80, Title 14, CCR) (Roberts and Gingras 2010).

Since 2007, regulations further changed the allowable White Sturgeon slot limit to 40.0 to 60.0 in (102 to 152 cm) FL. White Sturgeon that are 68 in (173 cm) FL or longer may not be removed from the water and shall be released immediately. The reduction in maximum length at the upper end of the slot limit and implementation of the 68 in (173 cm) water removal limit was intended to improve survival of larger fish that are important for reproduction and sustaining the fishery. The change to measuring FL instead of TL was implemented to combat poaching efforts in which some anglers would trim the outer end of a White Sturgeon's tail to make it fit within the designated slot limit. The use of snares and gaffs for landing White Sturgeon were banned in 1990 and 2013, respectively, to reduce discard mortality (§5.80, Title 14, CCR).

3.1.1. Overview and Rationale for the Current Management Framework

Current management of the White Sturgeon fishery allows a single fish from 40.0 to 60.0 in (102 to 152 cm) FL to be harvested per angler per day, and up to three fish to be harvested per angler in the calendar year (§5.80, Title 14, CCR). The current slot limit allows fish less than 40 in (102 cm) time to develop and mature, and also allows fish greater than 60.0 in (152 cm) FL to remain in the population to contribute to spawning, protecting the large fecund females that are important to maintaining the fishery (Hildebrand et al. 2016). The additional prohibitions surrounding the use of barbed hooks, gaffs or snares, and limits on removing fish over 68.0 in (173 cm) from the water, are designed to maximize survival rates in those fish that are caught but released.

3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild

Currently, no criteria have been identified to determine when the White Sturgeon fishery is overfished or in need of rebuilding. The Department is currently working with researchers from other agencies, universities and private companies to quantify and accurately model exploitation rates to determine if there is a need to limit White Sturgeon take in California. Current harvest is reported on the report cards, which are submitted at the end of each calendar year. In addition, the Department tags and attempts to re-capture fish each year to actively monitor the population size (mark-recapture population estimate). The number of tags returned by anglers divided by number of tagged fish released is used by the Department to calculate the harvest rate, and then the total retained catch (as reported by report cards) is divided by this rate to estimate the total population size (see section 1.2.1 and Figure 1-4). These types of information have been used to set regulations and propose fishery changes if needed on an ad hoc basis.

A recent attempt to model White Sturgeon population dynamics in the Central Valley population (Blackburn 2019) suggested that predicted population annual growth rates were negative when modeled using current slot limits. The modeling indicated that annual population growth rate was most sensitive to the mortality (exploitation rate + natural mortality) of sexually mature White Sturgeon. The trends in abundance and the work of Blackburn et al. (2019) suggest that the White Sturgeon population of the San Francisco Estuary may be over exploited and could benefit from changes to harvest regulations in order to reduce the exploitation rate.

3.1.1.2. Past and Current Stakeholder Involvement

The Department has engaged White Sturgeon anglers in the past to get public review and input before major regulation changes to the fishery, as well as to encourage disc tag returns. Tribal members have also provided input and recommendations for regulations, specifically with the issue of incidental catch of federally threatened Green Sturgeon in the North Coast District (Humboldt, Del Norte, Trinity, and Siskiyou counties).

3.1.2. Target Species

3.1.2.1. Limitations on Fishing for Target Species

3.1.2.1.1. Catch

The Department manages the fishery with the bag limit for recreational anglers of one fish per day and three fish per year statewide (§5.80, Title 14, CCR).

3.1.2.1.2. Effort

The recreational fishery effort is managed through the bag limits of one fish daily, an annual limit of three fish per angler, and the required report card; there is no additional limit to fishing effort for White Sturgeon (§5.79, Title 14, CCR; §5.80, Title 14, CCR).

3.1.2.1.3. Gear

White Sturgeon can only be taken using one single-point, single shank, barbless hook attached to a line. Gaffs, any type of firearm, or snare may not be used to take any sturgeon. Anglers with a second rod stamp with their fishing license may use a second rod to take sturgeon (§5.80, Title 14, CCR).

3.1.2.1.4. Time

The White Sturgeon fishery is open year-round, except for closures listed under special regulations including the central portion of San Francisco Bay, which is seasonally closed to White Sturgeon fishing from January 1 to March 15 (§5.80, Title 14, CCR; §27.95, Title 14, CCR).

3.1.2.1.5. Sex

Both sexes of White Sturgeon may be taken in the recreational fishery. White Sturgeon do not exhibit sexual dimorphism, so it is not possible to determine their sex unless mature individuals extrude gametes upon capture (Chapman et al. 1996).

3.1.2.1.6. Size

White Sturgeon ranging from 40.0 to 60.0 in (102 to 152 cm) FL may be retained. The fish must be measured from the tip of the nose to the far edge of the fork in the tail (§5.80, Title 14, CCR).

3.1.2.1.7. Area

Limits on White Sturgeon fishing in the upper Sacramento River include a closure from Keswick Dam to the Highway 162 Bridge from January 1 to December 31. No White Sturgeon may be taken within the North Coast District (including: Humboldt, Del Norte, Trinity, and Siskiyou counties) nor may they be taken in the Yolo Bypass, the Yolo Bypass Toe Drain Canal, or Tule Canal upstream of Lisbon Weir at any time (§5.80, Title 14, CCR). Additionally, no sturgeon may be taken in San Francisco Bay between January 1 and March 15 in the area bounded by a direct line between Point Chauncy and Pt. Richmond, the San Francisco-Oakland Bay Bridge and a direct line between Point Lobos and Point Bonita (§27.95, Title 14, CCR).

3.1.2.1.8. Marine Protected Areas

Pursuant to the mandates of the Marine Life Protection Act (FGC §2850), the Department redesigned and expanded a network of regional Marine Protected Areas (MPAs) in state waters from 2007 to 2012. The resulting network increased total MPA coverage from 2.7% to 16.1% of state waters. Along with the MPAs created in 2002 for waters surrounding the Santa Barbara Channel Islands, California now has a statewide scientifically-based ecologically connected network of 124 MPAs. The MPAs contain a wide variety of habitats and depth ranges.

White Sturgeon are thought to spend most of their life in estuaries, so it is unlikely that the network portion of open coast MPAs in which all recreational fishing is prohibited provides much protection to White Sturgeon. Additionally, those estuarine MPAs in the San Francisco Estuary do not prohibit recreational fishing and thus do not protect White Sturgeon.

3.1.2.2. Description of and Rationale for Any Restricted Access Approach

There is currently no restricted access program for White Sturgeon. Anyone with a fishing license and report card may lawfully fish for White Sturgeon (§5.79, Title 14, CCR; §5.80, Title 14, CCR).

3.1.3. Bycatch

3.1.3.1. Amount and Type of Bycatch (Including Discards)

FGC §90.5 defines bycatch as “fish or other marine life that are taken in a fishery but which are not the target of the fishery.” Bycatch includes “discards,” defined as “fish that are taken in a fishery but are not retained because they are of an undesirable species, size, sex, or quality, or because they are required by law not to be retained” (FGC §91). The term “bycatch” may include fish that, while not the target species, are desirable and are thus retained as incidental catch.

Limited information is available for bycatch during recreational angling for White Sturgeon. Many anglers catch and harvest additional species such as Striped Bass when targeting White Sturgeon, but there is no data available to quantify species composition or amount of bycatch caught. White Sturgeon not in the harvest slot limit are also frequent bycatch by anglers.

Data from the sturgeon report card program indicate that Green Sturgeon are also sometimes bycatch of the White Sturgeon fishery. In 2006, the National Marine Fisheries Service (NMFS) determined that the North American Green Sturgeon Southern Distinct Population Segment (DPS), which includes the populations originating from coastal watersheds south of the Eel River, is at risk of extinction in the foreseeable future throughout all or a significant portion of its range and listed the species as Threatened under the Federal Endangered Species Act (ESA). As a result, the Commission, upon a recommendation by the Department, closed the recreational fishery for Green Sturgeon in 2007 (§5.81, Title 14, CCR). In 2007, the Department began collecting data on angling effort and sturgeon catch via White Sturgeon report cards, which provide data on the number of Green Sturgeon caught in this fishery each year (Table 3-1). Anglers reported the catch and release of 230 Green Sturgeon in 2017, with an additional 27 sturgeon that could not be identified to species also released alive (DuBois and Danos 2018). There are a number of management measures in place to reduce the mortality of Green Sturgeon, including the use of barbless hooks, prohibitions on gaffing and snaring, and restrictions on removing Green Sturgeon from the water. While Green Sturgeon mortality after discard has not been formally studied, it is believed to be low.

Table 3-1. Number of Green Sturgeon released, White Sturgeon released, and White Sturgeon retained, 2007 to 2018 (CDFW White Sturgeon report card data, accessed June 2019).

Year	Green Sturgeon released	White Sturgeon released	White Sturgeon kept
2007	316	4,666	1,431
2008	240	5,103	1,786
2009	240	5,807	1,871
2010	163	4,372	1,424
2011	120	4,276	2,047
2012	176	4,224	1,747
2013	170	4,473	2,037
2014	186	4,680	2,331
2015	198	6,214	2,418
2016	221	5,074	2,595
2017	236	4,892	2,809
2018	210	4,164	2,147

The report card data also provides information on the number of released White Sturgeon, which has ranged from 1.5 to 6 times the number retained. It is unknown what proportion of released fish were too small or too large relative to the slot limit. Hooking mortality for sturgeon is not well quantified, but is assumed to be minimal. One study simulated capture handling (e.g. air exposure and struggling) without hooks on White Sturgeon and found that while some physiological stress occurs, it is likely to be minimal and sublethal (McLean et al. 2016).

There are no known interactions between the White Sturgeon fishery and either seabirds or marine mammals. In the San Francisco Estuary, there have been rare observations of sea lions biting at White Sturgeon that have been netted or hooked, but these have not resulted in any injury to the sea lion (Jason DuBois pers. comm.).

3.1.3.2. Assessment of Sustainability and Measures to Reduce Unacceptable Levels of Bycatch

The White Sturgeon fishery in the San Francisco Estuary is only recreational, so anglers often hook a suite of other fishes when targeting White Sturgeon. While bycatch information is limited for this fishery, the primary bycatch concern is for

Green Sturgeon, and secondarily the catch of oversized White Sturgeon (i.e., those fish larger than the slot limit that must be released). To address this, the Department has enacted a number of management measures to both track and mitigate bycatch of Green Sturgeon and oversized White Sturgeon. These include gear restrictions and prohibitions on removal of fish from the water to minimize stress and reduce mortality rates as well as mandatory report cards to track catches and releases.

3.1.4. Habitat

3.1.4.1. Description of Threats

Because White Sturgeon inhabit rivers and estuaries in heavily populated areas, they face a number of habitat threats. These include development along the coast and waterways, habitat fragmentation, pollution and contaminants, changes to river bed habitat, poaching, unscreened water diversions and invasive species (Zedler 1996; Schiff et al. 2000; Lotze et al. 2006; Roberts and Gingras 2010; Mussen et al. 2014). In addition, development of rivers for economic and flood control purposes has reduced the extent and complexity of White Sturgeon habitats across their range through channelizing, dredging, and other diversion practices. Construction and operation of dams has fragmented habitat, reduced water velocities, altered temperatures, and changed bottom compositions. These changes have influence on all life stages of White Sturgeon, and potentially hinder their survival and recruitment depending on severity and location (Hildebrand et al. 2016).

White Sturgeon recruitment success in the San Francisco estuary has been attributed to high “Delta outflow” (Stevens and Miller 1970; Kohlhorst et al. 1991; CDFG 2008; Fish 2010). Delta outflow is a measure of water permitted to flow through the Sacramento and San Joaquin river watersheds and through the Sacramento-San Joaquin Delta and downstream, rather than being diverted to storage or for agricultural and municipal users along the rivers or by the south Delta water export facilities. Changes in outflow due to competing demands for water may have detrimental impacts on nursery habitats for White Sturgeon.

The bay waters that White Sturgeon inhabit contain appreciable levels of selenium (Sun et al. 2019). Selenium accumulates in these areas due to agricultural runoff from areas of high natural occurrence in the soil, as well as from discharge from petroleum plants. In the Delta and Suisun Bay, selenium is bioaccumulated by two species of invasive clams (*Potamocorbula amurensis* and *Corbicula fluminea*) that are preyed upon by White Sturgeon, leading to further accumulation above thresholds thought to be associated with teratogenesis or reproductive failure (Stewart et al. 2004). Selenium concentrations of invasive clams collected from the Delta and Suisun Bay were well above levels necessary to produce toxic effects in juvenile Splittail (*Pogonichthys macrolepidotus*) in the laboratory (Stewart et al. 2004; Rigby et al. 2009). Studies are ongoing to learn more about its effects on White Sturgeon reproduction (e.g. Sun et al. 2019).

3.1.4.2. Measures to Minimize Any Adverse Effects on Habitat Caused by Fishing

While there are many potential threats to White Sturgeon habitat, the Department of Fish and Wildlife only has jurisdiction over those habitat impacts that stem from fishing activities. Only recreational angling by rod for White Sturgeon is allowed. This method of take has minimal adverse effects on the environment. The highest risk posed by this method is that of potentially snagging the substrate or submerged structure and breaking off gear and fishing line leaving it in the water. However, this impact is considered to be minimal, and no management measures to reduce habitat impacts are necessary at this time.

3.2. Requirements for Person or Vessel Permits and Reasonable Fees

As of 2019 anglers must pay the following fees in order to fish for White Sturgeon (Table 3-2). Current fishing permit and fee information is available at https://www.wildlife.ca.gov//Licensing//Fishing.

Table 3-2. California Department of Fish and Wildlife annual fishing fees for 2019. (Accessed September 2019. https://www.wildlife.ca.gov/Licensing/Fishing).

Title	Fee	Description
Resident Sport Fishing	$ 49.94	Available for any resident 16 years or older.
Non-resident Sport Fishing	$134.74	Available for any non-resident 16 years or older.
Second Rod Validation	$15.69	Allows a person to fish with two rods or lines in inland waters, except for waters in which only artificial lures or barbless hooks may be used.
Sturgeon Fishing report card	$8.64	Required for any persons taking sturgeon. Only one report card may be issued per person each year.
Guide License, Resident	$229.43	Any resident who engages in the business of guiding or packing, or who acts as a guide for any consideration or compensation at all, must first secure a guide license from the Department.
Guide License, Nonresident	$527.50	Any nonresident who engages in the business of guiding or packing, or who acts as a guide for any consideration or compensation at all, must first secure a guide license from the Department.

4. Monitoring and Essential Fishery Information

4.1. Description of Relevant Essential Fishery Information

FGC §93 defines Essential Fishery Information (EFI) as “information about fish life history and habitat requirements; the status and trends of fish populations, fishing effort, and catch levels; fishery effects on age structure and on other marine living resources and users, and any other information related to the biology of a fish species or to taking in the fishery that is necessary to permit fisheries to be managed according to the requirements of this code.” There are many studies on life history EFI for White Sturgeon as described in section 1, including age and growth, spawning patterns, diet, and movement. This section summarizes the EFI that is routinely collected and used to monitor the health of the stock. The Department relies on a combination of fishery-dependent and fishery-independent sources to monitor the status of the White Sturgeon fishery.

4.2. Past and Ongoing Monitoring of the Fishery

4.2.1. Fishery-dependent Data Collection

The Department manages the White Sturgeon fishery in part using angler-reported data (report cards) and CPFV logs. Both data sources provide an annual count of fish harvested, though CPFV catch data are a subset of report card data.

California anglers fishing in sturgeon-inhabited waters are required to purchase, complete, and return a report card for each calendar year. The report card has three sections: retained; released (no tag, also called a reward disk, present); and released (reward disk present). All sections provide space to record month, day, and location of catch. Anglers retaining White Sturgeon must record the length and, if present, the reward disk number. Anglers releasing sturgeon (no reward disk) must indicate the species by checking “White” or “Green.” For released sturgeon with a reward disk, the angler must record the disk number. Some anglers provide length data for released sturgeon, but this is not required.

Report cards are due by January 31 of the following year (e.g. 2018 report card is due by January, 31 2019). A web portal (https://www.ca.wildlifelicense.com/InternetSales/CustomerSearch/Begin) allows anglers to enter catch online, and recent trends indicate anglers are increasingly using this service. An angler also can mail in his/her report card. Returned report cards are sorted into three groups:

- did not fish;

- fished but caught no sturgeon; and
- fished and caught sturgeon.

To indicate "did not fish," the angler can easily mark the box "check here if you did not fish for sturgeon." Blank report cards or report cards with "zeroes" are considered fished with no catch. Anglers are not required to provide effort information (e.g. hours fished) or record days with no catch.

Report card data are summarized annually, typically around March or April the year following the report card year, and can be accessed on the Department website (http://www.dfg.ca.gov/delta/data/sturgeon/bibliography.asp). Report card data provide information on number of White Sturgeon harvested, number of sturgeon released, catch per angler, and length frequency distribution (though length for released sturgeon is not required). Additionally, report card data provide summaries of temporal (month or season) and spatial (catch location) fishing pressure (i.e., number of anglers) and catch (both retained and released).

CPFV log data provide a second source of fishery information. CPFV captains must complete and submit a log for each trip. Log data provide information about number of fish kept, number of anglers, trip duration (in hours), and location (or primary fishing block). Logs are entered by Marine Region personnel on an as-submitted basis.

Annually, the Department (Bay Delta Region 3) summarizes CPFV log data for successful trips (i.e., where at least one angler caught and kept one White Sturgeon fishing within the San Francisco Estuary). Because fishing effort is recorded, calculation of CPUE (catch per angler-hour) provides a quantitative measure of White Sturgeon relative abundance.

4.2.2. Fishery-independent Data Collection

The Department has intermittently conducted a sturgeon mark-recapture study since 1954 (annually since 2005, with exception of 2018). Fieldwork typically occurs August through October in Suisun and San Pablo bays. Using trammel nets, Department staff catch and measure (to nearest centimeter FL) all sturgeon. Species (White or Green) is also noted, along with fish condition (good, fair, poor), location, and net mesh size.

The current practice is to tag and release as many White Sturgeon between 100 to 200 cm (39 to 79 in) FL as feasible. A single Petersen disk tag is affixed just below the dorsal fin, such that the tag rests on the right side of the fish. Each tag offers a reward, with current denominations of $50, $100, and $150. Anglers must return the tag to the Department address printed on the tag to receive reward money. Anglers returning a disk tag are issued the appropriate reward along with a commendation card providing information about when and where the fish was tagged and thanking them for assisting in White Sturgeon fishery management.

Angler tag returns provide data for estimates of harvest rate and survival rate along with a crude measure of movement (i.e., where fish was tagged compared to where angler caught fish). Tag recaptures by the Department the year(s) following release provide data for estimates of absolute abundance (e.g. Petersen estimates) along with some measure of annual growth. A measure of relative abundance is calculated using catch and effort (i.e., soak or fishing time of each net set).

Aging White Sturgeon is time consuming, as it entails the physical removal of a small section of fin ray, and requires extensive laboratory work to prepare each fin-ray section for “reading”. Such reading has been done for collections made during 1973 to 1976 and 2014 to 2017 (Kohlhorst et al. 1991; Blackburn 2018; Blackburn et al. 2019). In the absence of direct aging, a length frequency distribution serves as a reliable surrogate for assessing year-class strength. Length frequency data are used in combination with a proximal age-length key to derive age frequency and thus brood year.

In addition to the adult fish sampled by trammel net, young sturgeon (age 0 to age 2-plus) are caught in the Department’s San Francisco Bay Study (Bay Study). Though not designed as a sturgeon-specific study, the Bay Study’s otter trawl data provide the only available young of the year (YOY) index for White Sturgeon in California (Fish 2010) (Figure 1-3). The YOY index identifies strong year-classes, which allows the Department to estimate when such year-classes will recruit to the fishery. Years 2006 and 2011 were the most-recently identified as strong year-classes. White Sturgeon begin to recruit to the fishery at age 8, so the 2006 year-class recruited in 2014 and the 2011 year-class in 2019.

5. Future Management Needs and Directions

5.1. Identification of Information Gaps

The current and most comprehensive assessments of data needs for White Sturgeon are Heublein et al. (2017) and Hildebrand et al. (2016), and are summarized below in Table 5-1. For California-based White Sturgeon, understanding factors affecting year-class strength and understanding spawning periodicity are subjects of ongoing research. In addition, data are limited for quantifying the catch-and-release portion of the fishery. While all data gaps listed in Table 5-1 are important, these were ranked in terms of priority for management using the following system:

- High: would have immediate value for making management decisions or informing models used to make management decisions.
- Medium: has important value for making long term decisions, some data/literature do exist but are incomplete.
- Low: increased understanding would definitely be helpful, but useful data do presently exist.

Table 5-1. Informational needs for White Sturgeon and their priority for management.

Type of information	Priority for management	How essential fishery information would support future management
Spawning periodicity	High	Allows for better estimation of annual spawning potential for long term management
Recruitment and survival of early life stages	High	Allows for better estimation of spawning success for long term management
Mortality of early life stages due to water diversions	High	Provides understanding of the impact that regional water demands may have on the population
Impact of predation on early life stages	High	Quantifies the extent to which predation by native and introduced species limits survival rate
Magnitude and impact of poaching	High	Clarifies how significant an impact the illegal take of migratory adults – primarily targeted on the largest, ripe females – has on the population
Critical habitats used by early life stages	Medium	Guides habitat protections and designations and water management decisions.
Movements, behavior, and habitat use by juveniles	Medium	Provides better understanding of the dynamics, vulnerabilities, and life history of juvenile White Sturgeon
Movements, behavior, and habitat use by adults	Medium	Provides better understanding of the dynamics, vulnerabilities, and life history of adult White Sturgeon

Type of information	Priority for management	How essential fishery information would support future management
Extent of spawning in the San Joaquin River system	Medium	Clarifies the contribution that the San Joaquin River makes to the total White Sturgeon population, and informs potential restoration efforts to increase access to spawning habitats
Effects of environmental variables on year-class strength	Medium	Provides understanding into how population dynamics may be impacted by variable or changing environmental conditions
Characterization of population dynamics and carrying capacity	Medium	Provides better understanding of long-term population trends and allows for more informed fisheries management
Effects of contaminants on all life stages	Medium	Guides restoration and management efforts related to contaminated spawning grounds, migration corridors, foraging grounds, and other key habitats
Validation of length-age relationships	Low	A more accurate determination of the age structure of the population aids population modeling and fishery management
White sturgeon dietary preferences	Low	Permits understanding of the impact invasive species, climate change, and changes in water management may have on the population.

5.2. Research and Monitoring

5.2.1. Potential Strategies to Fill Information Gaps

Possible strategies for filling the information gaps to better inform management of the White Sturgeon fishery include, but are not limited to:

- Expanding San Francisco Bay Study monitoring. This study, which has been ongoing since 1980, provides the only reliable White Sturgeon YOY index to date. Increased monitoring could provide information on critical habitats used by YOY, the effects of environmental variables on year-class strength, validation of length-age relationships, characterization of population dynamics, and movements and behavior of juveniles.

- Developing a routine annual survey specifically targeting age 0 and age 1 White Sturgeon to develop a comprehensive measure of YOY recruitment. Similar surveys using gill nets are presently conducted by Oregon and Washington as part of their routine management of White Sturgeon stocks. This study could also provide information on critical habitats used by YOY, the effects of environmental variables on year-class strength, validation of length-age relationships, characterization of population dynamics, and movements and behavior of juveniles.

- Expanding current adult mark-recapture sampling to include winter months (December, January, and February) and targeting other areas of the bay to increase the number of marked fish and possibly increase capture efficiency. Consider adding smaller and larger mesh sizes to better characterize fish on either side of the existing slot limit. Expanded mark-recapture sampling could inform validation of length-age relationships, characterization of population dynamics and carrying capacity; and movements, behavior, and habitat use by adults. Additional collection and analysis of pectoral fin rays could also be used to improve and validate existing length-age relationships.

- Continuing and expanding existing studies using egg-mat and larval net sampling in the Sacramento and San Joaquin rivers and tributaries. Such studies will help inform assessments of spawning success and early life stage recruitment, and can help clarify preferred spawning habitat and environmental characteristics.

- Establishing long-term acoustic tagging programs using small "smolt" tags for juveniles and larger, 10-year, 69 kilohertz tags for adults. Studies such as these would make use of the existing "core" acoustic receiver array to document movement patterns of juvenile and adult life stages, and adult migratory timing and potentially reproductive interval. A similar approach has been successful informing management of the southern DPS (DPS) Green Sturgeon population.

- Developing an annual adult spawner survey using sonar technologies (e.g. DIDSON, ARIS, sidescan) in known spawning reaches. This work could compliment an existing DPS Green Sturgeon adult spawner survey to produce routine, comprehensive surveys of sturgeon spawning runs in the Central Valley watershed.

- Better coordination with state and federal natural resource agency law enforcement to assess and limit the effects of illegal poaching.

- Studying diet, predation, and the effects of environmental variables and contaminants which may require a combination of laboratory experimentation, environmental monitoring, tissue sampling, and other experimental methods. Partnering with academic institutions could provide a useful avenue for evaluating these research needs.

5.2.2. Opportunities for Collaborative Fisheries Research

The Department has collaborated in the past and will continue to work with outside entities such as academic, governmental, and non-governmental organizations; citizen scientists; and both commercial and recreational fishery participants to help fill information gaps related to the management of state fisheries. The Department will also reach out to outside persons and agencies when appropriate while conducting or seeking new fisheries research required for the management of each fishery.

Recent collaborative efforts included working with university staff to implant acoustic tags into adult White Sturgeon. Further, the Department contracted with population modelers to evaluate long-term effects of exploitation on population dynamics (Blackburn 2018; Blackburn et al. 2019). Recently, United States Fish and Wildlife Service staff collected fin rays from White Sturgeon caught during the Department's mark-recapture study. Partnering with San Francisco Estuary Institute, the Department collected tissue samples for evaluation of selenium and other contaminant effects. Collaborative efforts will continue in the future as time, personnel, and needs dictate.

5.3. Opportunities for Future Management Changes

This section is intended to provide information on changes to the management of the fishery that may be appropriate, but does not represent a formal commitment by the Department to address those recommendations. ESRs are one of several tools designed to assist the Department in prioritizing efforts and the need for management changes in each fishery will be assessed in light of the current management system, risk posed to the stock and ecosystem, needs of other fisheries, existing and emerging priorities, as well as the availability of capacity and resources.

In the San Francisco Estuary over the period 2007 to 2018, White Sturgeon abundance was generally low and apparently declining. The Department continues to monitor effects of harvest on the adult White Sturgeon population. Possible future management considerations may include:

- reducing annual take (currently three per angler);
- changing the legal slot size (currently 40.0 to 60.0 in (102 to 152 cm) FL);
- restricting the fishery to something less than a full calendar year; and

- closing seasonal area; or
- combining any of the previous four considerations.

5.4. Climate Readiness

No action to prepare for climate change in the White Sturgeon fishery has been taken at this point; however, there are a number of possible ways in which climate change impacts might manifest themselves for this fishery. Climate change could impact White Sturgeon by altering the regional hydrography, changing the timing and magnitude of river flows. Successful year 0 recruitment is strongly correlated with wet years and high river flow, so shifting patterns in precipitation could result in earlier or narrower periods of high flow, or decreased flow in rivers resulting in reduced early life stage survival. Additionally, lower precipitation would result in decreased riverine inputs to estuaries, impairing important estuarine habitats, as well as increasing regional salinities and possibly water temperatures. Changes such as these could impact year-class strength. Managers can monitor river flow, as well as water conditions, to determine if these effects occur. Management actions could include increasing water releases from upstream reservoirs to mitigate the impacts of reduced rainfall or snow melt inputs.

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