PETITION TO LIST THE SAN FRANCISCO ESTUARY WHITE STURGEON (*Acipenser transmontanus*) POPULATION AS A THREATENED DISTINCT POPULATION SEGMENT UNDER THE ENDANGERED SPECIES ACT with CRITICAL HABITAT

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Petitioners

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RESTORE THE DELTA For a Healthy Estuary and Community

CALIFORNIA SPORTFISHING PROTECTION ALLIANCE CSPA * Since 1983 *

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1. Executive Summary

The White Sturgeon (*Acipenser transmontanus*) is the largest freshwater fish species in North America. The species as a whole is considered to be "endangered" by the American Fisheries Society (AFS 2008). Reproducing populations occur in the Columbia River and Fraser River Basins and in California, where the only such population occurs in the Central Valley (Sacramento River and San Joaquin River watersheds). The landlocked White Sturgeon population of the Kootenai River (a tributary of the Columbia River) is listed as endangered under the federal Endangered Species Act (ESA). White Sturgeon that spawn in the Central Valley and rear and/or migrate through the San Francisco Bay Estuary (SFE) are regarded as a species of "High" management concern by California Department of Fish and Wildlife (CDFW 2015); hereafter we refer to this population as the SFE White Sturgeon population.

Studies indicate that annual recruitment of SFE White Sturgeon has decreased since the early 1980s. Recent evidence indicates that this decline is continuing (Blackburn et al. 2019; Ulaski et al. 2022). Environmental conditions necessary to support population viability are deteriorating (SWRCB 2017; CDFW 2023). High levels of water diversion combined with adverse reservoir storage operations generate extremely altered hydrographs throughout the SFE watershed (TBI 2016; SWRCB 2016, 2017; Reis et al. 2019) – where SFE White Sturgeon spawn and rear – impairing successful reproduction. The population also suffers from overharvest in the recreational fishery (Blackburn et al. 2019; CDFW 2023; California Fish and Game Commission 2023). Furthermore, a massive harmful algal bloom in San Francisco Bay and San Pablo Bay in 2022 killed large numbers of adult SFE White Sturgeon, demonstrating the population's vulnerability to future algal blooms (CDFW 2023). A smaller harmful algal bloom in 2023 caused additional mortality to adult SFE White Sturgeon – 15 dead adults were detected on the shoreline by community scientists in the vicinity of the bloom soon after it occurred (California Fish and Game Commission 2023). SFE White Sturgeon population growth is most sensitive to survival of sexually mature adults (Blackburn et al. 2019), so these consecutive fish kills almost certainly have exacerbated the chronic declines in SFE White Sturgeon abundance. Persistent blooms in the Delta are likely to impede SFE White Sturgeon migration to and from their spawning grounds in the San Joaquin River watershed. Harmful algal blooms are fueled by chronically high nutrient levels in the SFE (Cloern et al. 2020); bloom formation in the Delta is also tied to high levels of water diversion and subsequent high residence time (low flow) in certain Delta channels (Berg and Sutula 2015).

Existing environmental regulations are inadequate to prevent further decline; without additional protections afforded to species listed under the Endangered Species Act (ESA), the SFE White Sturgeon is increasingly likely to become endangered in the near future. Current regulation of river flow and water quality conditions in the SFE are inadequate to support native fish viability and fisheries (SWRCB 2010, 2017; CDFW 2010), including SFE White Sturgeon. The prospect of increasingly frequent and prolonged droughts related to global climate change (Diffenbaugh et al. 2015), combined with several planned water development projects in the SFE watershed are likely to increase the frequency and severity of inadequate river flow conditions in the future. Similarly, current White Sturgeon fishing regulations are not sufficiently protective to prevent further decline of the population (Blackburn 2019; CDFW 2023; California Fish and Game Commission 2023) and future regulations under development now are inadequate to maintain population stability, much less reverse the decline of the SFE White Sturgeon population. Finally, harmful algal blooms in San Francisco Bay proper, which are facilitated by nutrient enrichment, threaten to cause repeated mass mortality events for SFE White Sturgeon in the future. Regulations to limit nutrient pollution to levels that will prevent harmful algal blooms have not yet been proposed and are not likely to be completely implemented for at least a decade. Meanwhile, water quality conditions in the Delta, particularly in the San Joaquin River near Stockton, likely impair migration of adult and juvenile SFE White Sturgeon to and from spawning grounds in the San Joaquin basin. More protective flow standards for the lower San Joaquin River have been adopted by the State Water Resources Control Board (SWRCB 2018); however, five years later, the state has yet to implement these standards.

Each of these major impacts — inadequate river flow and water quality conditions, overharvest, and the loss of habitat and potential for catastrophic mortality due to harmful algal blooms — represent a grave threat to the SFE White Sturgeon population. These problems are independent of each other – addressing just one or two of these major problems will not eliminate the high risk that SFE White Sturgeon become endangered – that is, experience further declines in viability such that it is in danger of extinction – in the near future. Also, SFE White Sturgeon are impacted by numerous other environmental stressors that threaten the population. A coordinated response to these individual and collective threats is required in order to prevent endangerment and then extirpation of this unique population.

For these reasons, we petition the National Marine Fisheries Service to list the SFE White Sturgeon population as threatened, meaning it is “likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.” 16 U.S.C. § 1532(20).

2. Legal and Regulatory Framework

2.1. ESA Summary

The Endangered Species Act (ESA) was enacted in 1973 to protect “fish, wildlife, and plants” which were deemed to be at risk of extinction and/or scientifically significant. See 16 U.S.C. § 1531(a). Specifically, the goals of the ESA are to “provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, to provide a program for the conservation of such endangered species and threatened species, and to take such steps as may be appropriate” pursuant to treatises and conventions to which the United States is a party. See 16 U.S.C. § 1531(b).

The ESA is jointly administered by the Fish and Wildlife Service (FWS) in the Department of the Interior and the National Marine Fisheries Service (NMFS) in the Department of Commerce, but it is also "the policy of Congress that all Federal departments and agencies shall seek to conserve endangered species and threatened" species while working cooperatively with state and local agencies. 16 U.S.C. § 1531(c).

The FWS and NMFS are tasked with determining whether a species is endangered or threatened, as well as designating the critical habitat of such species and preparing a recovery plan for each listed species. 16 U.S.C. § 1533(a)(1)-(3). Determinations made under the ESA are to be made with "the best scientific and commercial data available." 16 U.S.C. § 1533(b). FWS has primary jurisdiction over terrestrial and freshwater organisms, while NMFS has jurisdiction mainly over marine wildlife, such as marine mammals and anadromous fish.

In addition to reviewing the best scientific data available, when determining whether a species is endangered or threatened, FWS and NMFS must evaluate five listing factors set forth in 16 U.S.C. § 1533(a)(1):

1. The present or threatened destruction, modification, or curtailment of its habitat or range;
2. Overutilization for commercial, recreational, scientific, or educational purposes;
3. Disease or predation;
4. The inadequacy of existing regulatory mechanisms; or
5. Other natural or manmade factors affecting its continued existence.

A species need only meet one of the listing criteria outlined in the ESA to qualify for federal listing. 50 C.F.R. § 424.11(c).

2.2. DPS Designation Standard

The ESA defines species as ''any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife that interbreeds when mature.'' 16 U.S.C. § 1532(16). This definition allows for the recognition, listing, and protection of distinct population segments (DPS) at levels below taxonomically recognized species or subspecies. On February 7, 1996, the FWS and NMFS published a joint policy to clarify the phrase ''distinct population segment'' for the purposes of listing, delisting and reclassifying species under the ESA (61 FR 4722). That policy considers three elements to be relevant to a decision regarding the status of a possible DPS as endangered or threatened under the ESA:

1. Discreteness of the population segment in relation to the remainder of the species to which it belongs;
2. The significance of the population segment to the species to which it belongs; and
3. The population segment's conservation status in relation to the ESA's standards for listing (i.e., is the population segment, when treated as if it were a species, endangered or threatened?).

2.2.1. Discreteness

A population segment of a vertebrate species may be considered discrete if it satisfies *either* of the following conditions:

1. It is markedly separated from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors. Quantitative measures of genetic or morphological discontinuity may provide evidence of this separation.
2. It is delimited by international governmental boundaries within which differences in control of exploitation, management of habitat, conservation status, or regulatory mechanisms exist that are significant in light of section 4(a)(1)(D) of the ESA.

2.2.2. Significance

Population segments that are considered discrete must also demonstrate biological and ecological significance to qualify as a listable DPS; this requirement is intended to account for Congressional guidance (see S. Rep. No. 151, 96th Cong., 1st Sess. (1979)) that the authority to list DPSs be used ‘‘sparingly’’ while encouraging the conservation of genetic diversity. In carrying out this examination, available scientific evidence of the discrete population segment's importance to the taxon to which it belongs is considered. This consideration may include, but is not limited to, the following:

1. Persistence of the discrete population segment in an ecological setting unusual or unique for the taxon,
2. Evidence that loss of the discrete population segment would result in a significant gap in the range of a taxon,
3. Evidence that the discrete population segment represents the only surviving natural occurrence of a taxon that may be more abundant elsewhere as an introduced population outside its historic range, or
4. Evidence that the discrete population segment differs markedly from other populations of the species in its genetic characteristics.

2.3. Critical Habitat Standard

Critical habitat under the ESA, defined at 16 U.S.C. § 1532(5), is:

> "(i) the specific areas within the geographical area occupied by a species, at the time it is listed in accordance with the provisions of [section 1533 of this title], on which are found those physical or biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) the specific areas outside the geographical area occupied by the species at the time it is listed in accordance with the

> provisions of [section 1533 of this title], upon a determination by the Secretary that such areas are essential for the conservation of the species."

As recognized by Congress, the protection of habitat is essential to the recovery and/or survival of listed species:

> "[C]lassifying a species as endangered or threatened is only the first step in insuring its survival. Of equal or more importance is the determination of the habitat necessary for that species' continued existence. […] If the protection of endangered and threatened species depends in large measure on the preservation of the species' habitat, then the ultimate effectiveness of the Endangered Species Act will depend on the designation of critical habitat." H. Rep. No. 94-887, 94th Cong., 2d Sess. at 3 (1976).

3. Natural History

3.1. Description

The California Department of Fish and Wildlife (CDFW) describes White Sturgeon as follows:

> "… adults have wide, rounded snouts, with four barbels in a row on the underside, closer to the tip of the snout than to the mouth (Moyle 2002). They feed with a toothless, highly protrusible mouth and process food with a palatal organ in the pharynx. Their bodies have 5 widely separated rows of bony plates (scutes). Scute counts per row are: 11-14 (dorsal row), 38-48 (two lateral rows) and 9-12 (bottom rows). Four to eight scutes are also found between the pelvic and anal fin. Although they lack the large scutes behind the dorsal and anal fins found in green sturgeon (*A. medirostris*), small remnant scutes (fulcra) may be present. The dorsal fin has one spine followed by 44-48 rays. The anal fin has 28-31 rays. The first gill arch has 34-36 gill rakers. Body coloration is gray-brown on the dorsal surface above the lateral scutes, while the ventral surface is white and fins are gray. Their viscera are black. Dispersing juveniles tend to be darker than dispersing free embryos (Kynard and Parker 2005). Juveniles less than one year old have 42 dorsal fin rays, 35 lateral scutes, and 23 gill rakers on the first arch." (CDFW 2015 at p. 224.)

White Sturgeon may grow to 6 m fork length (FL), live more than 100 years, and weigh over 600 kg. In California, the largest individual on record – caught in Lake Shasta in 1963 – measured 2.9 m and 225 kg, and was at least 67 years old (CDFW 2015 at p. 225).

3.2. Taxonomy

All modern sturgeon are polyploid; White Sturgeon belong to ploidy group B with 240 chromosomes (Hildebrand et al. 2016). Phylogenetic relationships revealed by analysis of multiple mitochondrial gene sequences indicate that White Sturgeon's closest relatives are Asian species, including *A. schrenckii*, *A. sinensis*, and *A. dabryanus* (Krieger et al. 2008; Hildebrand et al. 2016). Analysis of multiple mtDNA sequences suggested that White Sturgeon shared a common ancestor with *A. schrenckii* (Amur Sturgeon) approximately 46 million years ago (Hildebrand et al. 2016 citing Peng et al. 2007).

3.3. Range

Reproducing populations of White Sturgeon have been documented in the Sacramento, San Joaquin, Columbia, and Fraser River drainages (Hildebrand et al. 2016). Land-locked populations exist in the Columbia River basin above major dams (Figure 1). White Sturgeon have also been introduced to watersheds outside of their native range (Figure 1) but none of these introduced populations appears to have persisted (USGS; https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=300). In California, White Sturgeon spawning is documented only in the Sacramento River (Moyle 2002; CDFW 2015) and in the San Joaquin River (Jackson et al. 2016). Spawning probably occurs, or occurred historically, in other reaches of major Central Valley Rivers (Moyle 2002). For instance, the National Marine Fisheries Service (NMFS) reports that "Green and white sturgeon adults have been observed periodically in small numbers in the Feather River" (17388 Federal Register/Vol. 70, No. 65 citing Beamesderfer et al. 2004). White Sturgeon have been detected in California river systems north of the SFE (Figure 2), but the origins and reproductive fates of these fish are unknown; CDFW (2015) reports:

> "Historically, small runs also occurred in the Russian, Klamath and Trinity rivers. White sturgeon have also been documented in the Eel River (M. Gilroy, CDFW, pers. comm. 2011). It is doubtful that any of these latter four rivers currently support populations of white sturgeon."

In salt water, White Sturgeon have occasionally been found far from likely natal rivers, including in the Aleutian Islands, and near Baja California, Mexico (Hildebrand et al. 2016 citing PSMFC 1992 and Ruiz-Campos et al. 2011, respectively). Individuals tagged in the SFE have been recaptured outside of their natal basin, including one in the Lower Fraser River (Welch et al. 2006) but it is generally thought that long-distance marine migrations of White Sturgeon are infrequent (Drauch Schreier et al. 2013). In the SFE, White Sturgeon may occasionally be found in tidal habitats of larger tributary streams such as Coyote Creek, the Guadalupe River, the Napa River, Sonoma Creek, and the Petaluma River (Leidy 2007 citing Stevenson et al. 1987 and CDFG 2006).

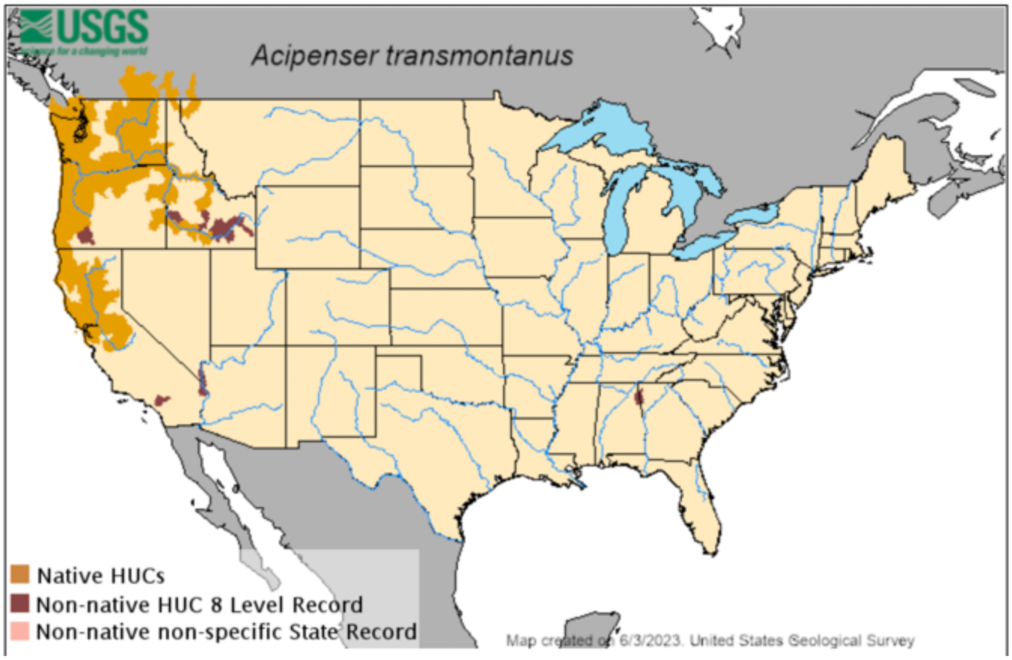


Figure 1: Native range of White Sturgeon (Acipenser transmontanus) in the lower 48 United States. Documented introductions outside of the native range are also depicted. USGS; https://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=300

The small spawning range of SFE White Sturgeon relative to its large body size is characteristic of most endangered fish species in North America (Rosenfield 2002). The challenges of maintaining adequate population size and geographic insulation from localized catastrophic events are magnified for distinct populations of large-bodied fishes, like the SFE White Sturgeon, that are more geographically constrained than the species as a whole.

3.4. Habitat Requirements

White Sturgeon populations with access to marine environments spawn in large rivers when flows are elevated and generally rear in their natal river estuaries and local marine environments until maturation and between spawning events (CDFW 2015; Hildebrand et al. 2016; Sellheim et al. 2022). Although they display wide diversity in their use of saline environments, SFE White sturgeon spawn exclusively in freshwater and spend most of their lives in saline habitats, returning to freshwater environments to spawn. Therefore, NMFS has jurisdiction over SFE White Sturgeon under the federal ESA. Indeed, the migratory behavior of non-landlocked White Sturgeon populations is roughly analogous to that of Shortnose Sturgeon (*Acipenser brevirostrum*) of the Atlantic Coast, a federally endangered species administered by NMFS.

White Sturgeon spawn in deep water (>4m; Parsley and Beckman 1994) with swift currents. Jackson et al. (2016) collected eggs in the San Joaquin River at depths >10 m. Spawning occurs at temperatures from 8 -19°C, and peaks at ~14°C (CDFW 2015 citing McCabe and Tracy 1994). CDFW (2015) states that optimal incubation substrate is free of sand and silt that can smother embryos. Spawning substrates in the San Joaquin River and Kootenai Rivers may contain some gravel, but are dominated by sand, silt, or hard pan clay (Hildebrand et al. 1996 citing Jackson, Z., USFWS, Lodi, CA, pers. comm., and Kohlhorst, 1976); perhaps as a result, there is no White Sturgeon recruitment in the Kootenai River (Paragamian 2012) and successful recruitment in the San Joaquin River probably occurs only during years with high river flow (A. Schreier, UC Davis, pers. comm., Oct. 31, 2023).

In the SFE, recently hatched White Sturgeon employ a two-stage dispersal from spawning sites to estuarine rearing habitats. Partially developed White Sturgeon hatchlings are photonegative and briefly disperse along river bottoms; these embryonic fish then seek benthic cover until the initiation of exogenous feeding (Kynard and Parker 2005). Under optimal thermal conditions (14-17°C), SFE White Sturgeon eggs hatch in approximately 5-7 days and yolk sack absorption is completed approximately 20-23 days post-fertilization (Wang et al. 1985). SFE White Sturgeon YOY are able to feed exogenously 20-30 days after hatching, at which point they swim downstream actively, dispersing widely into rearing habitat throughout the lower rivers and Delta (Israel et al. 2009 citing McCabe and Tracey 1994; Kynard and Parker 2005). As YOY, SFE White Sturgeon become tolerant of brackish waters and tolerance or preference for salinity appears to increase continually with age (Sellheim et al. 2022).

In estuarine environments, White Sturgeon aggregate in deep water over soft bottom substrates. Movements may be in response to changes in salinity (CDFW 2015 at p. 224) and/or freshwater inflow to the estuary (Hildebrand et al. 2016 citing Kolhorst 1991). White Sturgeon feed on or near the bottom; they may feed in intertidal areas during high tides (Moyle 2002; CDFW 2015) but otherwise prefer deep water environments. Prey for juvenile sturgeon include chironomids, amphipods, aquatic insect larvae, and opossum shrimp (*Neomysis mercedis*; Scott and Crossman 1973; CDFW 2015). As White Sturgeon grow, their diet is dominated by benthic invertebrates including crabs and clams. An invasive non-native clam, *Corbula amurensis*, has become a major SFE White Sturgeon prey item since its invasion in the late 1980s, though its nutritional value to sturgeon is unknown (Zeug et al. 2014). Larger White Sturgeon prey on a range of fish including Pacific Herring (adults and eggs), Anchovy, Striped Bass, Starry Flounder, and Longfin Smelt (Skinner 1962; Scott and Crossman 1973; CDFW 2015 at p.225; Zeug et al. 2014).

Although capable of marine migrations (as evidenced by records of White Sturgeon along the Pacific Coast, far from natal habitats), SFE White Sturgeon typically remain in brackish estuarine environments through most or all of their adult lives (Miller et al. 2020). Until recently, it was believed that most White Sturgeon juveniles and adults remain in the SFE year-round (Klimley et al. 2015), but isotope microchemistry evidence reveals considerable individual variation in migrations to and from marine environments. Sellheim et al. (2022) found a wide range of amphidromous behavior among sub-adult SFE White Sturgeon (i.e., during the first 10 years of life), which they grouped into four basic patterns "ranging from those that primarily inhabited low salinity waters to those who resided in high salinity water following a few years in low or medium salinity" (at p. 11). Although some sub-adults remained in freshwater environments throughout their pre-maturation period, others never occupied freshwater during their sub-adult years. Short duration movements into high salinity habitats (> 10 psu) occurred among approximately half of the White Sturgeon studied by Sellheim et al. (2022) and the frequency of journeys into higher-salinity brackish habitats increased as individuals aged.

In addition to these periodic and short-term movements into marine waters, longer distance marine movements have been documented (Scott and Crossman 1973). Such migrations explain observations of juvenile and sub-adult White Sturgeon far from known spawning populations (Hildebrand et al. 2016). However, long-distance marine dispersal does not appear to be a significant component of the White Sturgeon life history strategy; gene flow appears to attenuate with geographic distance (Drauch Schreier et al. 2013; Willis et al. 2022), suggesting that extensive migrations are most often associated with feeding rather than spawning (CDFW 2015 at p. 225).

3.5. Life History

Hildebrand et al. (2016) provided a rangewide overview of White Sturgeon life history stages. SFE White Sturgeon spawn and develop one to several months earlier than populations elsewhere in their range (see Hildebrand et al. 2016 at Table 1).

White Sturgeon are iteroparous. A small proportion of adults spawn in any given year. Successful reproduction occurs episodically, when spring-summer river flows are high enough to support incubation and early rearing success. In the SFE, females may mature reproductively as early as age 10, but more commonly between ages 12-16 (95-135 cm FL); 50% of females mature by age 14 and all mature by age 19 (CDFW 2015; Blackburn et al. 2019; CDFW 2023). Males mature earlier, generally between 10-12 years of age (75-105 cm FL), and appear to spawn more frequently than females (Willis et al. 2022). Following maturation, males may spawn every 1-2 years. Females are physiologically capable of spawning every 2-3 years (Hildebrand et al. 2016 citing Paragamian et al. 2005); they typically wait at least 2-4 years between reproductive events, longer if spawning conditions are not favorable (Moyle 2002 at p. 108). Adult SFE White Sturgeon prepare to spawn by moving into the lower reaches of Central Valley rivers during the winter months and migrate upstream into spawning areas between December and late May or early June (Israel et al. 2009; CDFW, 2015, pp. 225-226; Hildebrand et al. 2016; CDFW 2023).

Fecundity of female SFE White Sturgeon averages 5,648 eggs per kilogram of body weight, which translates to hundreds of thousands of eggs per female at maturity (CDFW 2015 citing Chapman et al. 1996; Klimley et al. 2015; Willis et al. 2022). Eggs are negatively buoyant and become adhesive upon fertilization (Moyle 2002; Israel et al. 2009; Hildebrand et al. 2016). Embryonic development is rapid and temperature-dependent, ranging from 3-13 days in the SFE White Sturgeon population. Optimal egg incubation occurs between 14-17°C; mortality is nearly complete at temperatures <8°C and > 20°C (Wang 1985; CDFW 2023). Hildebrand et al. (2016) suggest that populations may differ in their upper lethal temperature.

Among SFE White Sturgeon, yolk-sac larvae are 10-11mm total length (TL) at hatch; at temperatures between 14°C and 17°C, the yolk sac is completely absorbed approximately 20-23 days post-fertilization (Wang et al. 1985). Larvae are photonegative upon hatching and swim near the bottom of rivers (Kynard and Parker 2005). In a laboratory study, the presence of physical cover in well-lit mesocosms decreased predation on White Sturgeon larvae <17 mm TL; however, larger individuals did not benefit from the presence of cover and other studies have observed that White Sturgeon leave cover at the size where exogenous feeding begins (Gadmoski and Parsley 2005).

Recruitment of juvenile SFE White Sturgeon is positively correlated with high river flows and Delta Outflow during spring and early summer months (Israel et al. 2009; CDFW 2015, 2023; SWRCB 2017; *see also* Parsley and Beckman 1994; AFRP 2001; Moyle 2002; Willis 2022). CDFW's conceptual model for SFE White Sturgeon life history states:

> "The dispersal of larval white sturgeon is dependent on high spring river flows, which optimally consists of multiple large flow pulses and a relationship between the mean monthly outflow from April–July and white sturgeon [young-of-year] has been developed (Kohlhorst et al. 1991). Reduced seasonal flows or flows mismatched ecologically with sensitive early life stages may reduce dispersal of these life stages when they are most vulnerable to native and nonnative predation. Flow reductions may serve to reduce or eliminate [young-of-year] survival even if spawning was successful." (Israel et al. 2009 at p. 17).

The mechanism underlying the relationship between high river flows and SFE White Sturgeon recruitment has been attributed to improved survival and transport of larval sturgeon into suitable rearing areas, increases in the number of females spawning during high flow periods, or both (Fish 2010; CDFW 2015 at p. 226). It is also possible that high river flows improve spawning habitat by cleaning sand and silt out of gravel and cobble spawning substrates (Paragamian 2012; Hildebrand et al. 2016). Juvenile sturgeon actively swim downstream towards the estuary, suggesting that their capacity to osmoregulate in brackish environments develops as larvae mature into juvenile fish (Israel et al. 2009; CDFW 2015 citing McEnroe and Cech 1987). In the Central Valley, SFE White Sturgeon spawning has been detected during wet and dry years in both the San Joaquin River and the Sacramento River, indicating that adults will attempt to spawn even when flows are low (Jackson et al. 2016). The fact that juvenile recruitment appears to be successful only in years when elevated river flows occur during larval dispersal and early juvenile rearing (i.e., between April and July) suggests that flows during the spring and early summer are essential (SWRCB 2017). CDFW (2015 at p. 227) states: "The first few months of life are considered to be critical for sustaining populations [of White Sturgeon]."

SFE White Sturgeon appear to grow more rapidly than conspecifics in more northerly populations. Young-of-year (YOY) White Sturgeon reach 18-30 cm TL by the end of their first year in the SFE, before growth rates slow such that they reach 102 cm TL by Age 7 or 8. SFE White Sturgeon grow faster than fish from any other populations through age 10 and growth remains fast relative to most populations throughout their life span (*see* Figure 2 of Hildebrand et al. 2016). SFE White Sturgeon are predicted to reach approximately 147 cm length by age 15, whereas fish of the same age in the lower Columbia River are predicted to be 116 cm (Blackburn et al. 2019, citing DeVore et al. 1995). SFE White Sturgeon in the SFE grow approximately 4.6 cm/year between ages 10-50, whereas those in the Kootenai River grow approximately 2.5 cm/year (Blackburn et al. 2019 at p. 907, citing Paragamian et al. 2005).

The relatively rapid growth of SFE White Sturgeon may reflect availability of water temperatures and/or high-quality habitats that support rapid growth, weak or absent density-dependence (i.e., low competition), or elevated marine-based prey availability. Alterations in hydrology resulting from dam operations are also suspected to produce differences in White Sturgeon growth (Blackburn et al. 2019 at p. 907, citing Beamesderfer et al. 1995 and Van Poorten and McAdam 2010). Whether this phenotypic difference in growth rates has any genetic basis is unknown.

In the SFE, White Sturgeon larger than 2 m and older than 27 years are not common (CDFW 2015 at p. 225). Blackburn et al. (2019 at p. 906) reported a maximum age of 29 years, although they acknowledged uncertainty in estimation of age for fish older than 20 years old. They attributed truncated maximum age span in the SFE to harvest and sampling gear bias (the trammel net gear used by CDFW's Adult Sturgeon Study has a mesh size that targets legal-sized fish; oversized fish are captured less frequently).

3.6. Natural Mortality

Natural mortality of adult and sub-adult fish is expected to be low. Adult sturgeon are heavily armored and extremely large relative to most potential predators. White Sturgeon may be preyed upon by large sharks, sea lions, and other marine mammals (CDFW 2023, https://marinespecies.wildlife.ca.gov/white-sturgeon/the-species/), but mortality due to predation on adults is likely to be rare. Reliably high adult survival is essential to the success of the White Sturgeon life history strategy, which features late maturation, iteroparity, and multi-year intervals between spawning attempts.

On the other hand, larval and early juvenile White Sturgeon are susceptible to predation prior to ossification of their bony scutes (Gadomsky and Parsely 2015). Rates of predation on larval and juvenile White Sturgeon are unknown. In the SFE and its watershed, Sacramento Pikeminnow (*Ptychocheilus grandis*), Channel Catfish, (*Ictalurus punctatus*), Prickly Sculpin (*Cottus asper*), Common Carp (*Cyprinus carpio*), Largemouth Bass (*Micropterus salmoides*), and Striped Bass (*Morone saxatalis*) are likely to prey opportunistically on larval and juvenile White Sturgeon (CDFW 2015; see https://marinespecies.wildlife.ca.gov/white-sturgeon/the-species/). Predation would be expected to increase under low river flow conditions, which correspond to lower river stage and reductions in suspended sediment, both of which enable light penetration to the dark benthic environments that provide cover for larval and juvenile White Sturgeon.

3.7. Status

Twenty-two species in the order Acipenseriformes (sturgeon and paddlefishes) are categorized as “extinct in the wild”, ‘‘critically endangered’,’ or ‘‘endangered’’ by the International Union for Conservation of Nature
(IUCN: https://www.iucnredlist.org/search/list?query=sturgeon&searchType=species). The most recent IUCN list categorizes White Sturgeon as “vulnerable;” the change from the previous IUCN rating as "least concern" reflects this fish’s declining status range-wide. White Sturgeon populations in the Columbia River above Grand Coulee Dam, Kootenai River, Fraser River and Nechako River are recognized as threatened or endangered by the United States and/or Canadian governments (Hildebrand et al. 2016; Ulaski et al. 2022 at p. 335). The American Fisheries Society considers White Sturgeon to be “endangered” (AFS 2008).

The SFE population of White Sturgeon – the only reproducing population in California – is a Species of Special Concern (CDFW 2015; Hildebrand et al. 2016). The 1992 Central Valley Project Improvement Act (CVPIA) established as federal policy that ‘‘natural production of anadromous fish in Central Valley rivers and streams will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967–1991.” (CVPIA §3406(b)(1)). Under this “doubling policy”, the Anadromous Fish Restoration Program (AFRP) established a production target of 11,000 White Sturgeon in the Central Valley, wherein “production” refers to the number of first-time spawners each spawning season (AFRP 2001 appendix A-2, *sensu* Ricker 1958). The AFRP Final Plan identifies as a “high priority” the need to “[s]upplement Delta outflow for migration and rearing of white sturgeon, green sturgeon, striped bass, and American shad by modifying [Central Valley Project] operations…” (AFRP 2001 at 97). Despite habitat and ecosystem restoration projects funded by the CVPIA and other governmental programs, there is no evidence that the AFRP White Sturgeon production target has ever been attained (Ulaski et al. 2022 at p. 335).

Like most sturgeon species, White Sturgeon life history allows them to capitalize on spawning, incubation, and juvenile rearing conditions that are available only infrequently. Historically, their long-life spans, variable and opportunistic reproduction, and high fecundity made it possible for SFE White Sturgeon to persist and maintain a relatively stable population through periods when riverine spawning and early rearing habitats were unsuitable (e.g., due to low river flows associated with drought conditions). However, as the State Water Resources Control Board (SWRCB) noted, the SFE White Sturgeon population currently “does not appear stable and exhibits progressively diminishing recruitment in recent wet years” (SWRCB 2017 at p. 3-63).

Although longevity and fecundity may buffer populations through periods of low recruitment, delayed maturation and the multi-year interval between egg clutches of individual females also make White Sturgeon vulnerable to sustained anthropogenic modification of river and estuarine flow regimes, overharvest, and sustained degradation of other habitat conditions (Blackburn et al. 2019). Willis et al. (2022 at p. 2) cautioned: “…long-term viability of white sturgeon depends on regularly favorable climate and flow conditions, as well as access to appropriate spawning and rearing habitat.” See Hildebrand et al. 2016. The low intrinsic population growth rate of

White Sturgeon means it is highly sensitive to overharvest (Blackburn et al. 2019; Ulaski et al. 2022 citing Boreman 1997) and catastrophic adult mortality events. Furthermore, because White Sturgeon recruitment is heavily influenced by survival at early life stages (Jackson et al. 2016 at p. 172 citing Kohlhorst et al. 1991, Hildebrand et al. 1999, Secor et al. 2002), persistent reduction in the frequency of high magnitude spring-summer river flows leads to increases in the interval between successful cohorts, reducing the population's resilience and viability during periods of poor recruitment or high levels of sub-adult/adult mortality.

3.8. Changes in Distribution

Adequate distribution of spawning and rearing sites (population spatial structure) is a key factor determining the viability of anadromous fish species (McElhany et al. 2000). When key life stages are confined to a few small locations, the entire population is at risk from localized catastrophic mortality or destruction of habitat (Rosenfield 2002). The current distribution of SFE White Sturgeon spawning is highly constrained relative to the population's historic range (Figure 2).

Impassable dams have blocked access to important spawning habitats throughout the Central Valley (CDFW 2015). Indeed, Sellheim et al. (2002 at p. 2) observed that "Much of historical California freshwater spawning and rearing habitat is now either inaccessible or severely degraded due to impassable barriers, insufficient freshwater flows, agricultural diversions, elevated water temperatures, invasive species, and environmental contaminants such as selenium." A relic population that persisted in Shasta Reservoir after construction of Shasta Dam indicates that SFE White Sturgeon likely migrated and spawned upstream of the current damsite historically, including in major tributaries to the upper Sacramento River such as the Pit River (Moyle 2002; CDFW 2015). Spawning in the Sacramento River is believed to occur only in the 140 km reach between Knights Landing and Colusa (Moyle 2002; CDFW 2015). In the San Joaquin River, spawning has been documented at sites between rkm 115.2 and rkm 139.8 (Jackson et al. 2016). NMFS reports "periodic" spawning of White Sturgeon in the Feather River (17388 Federal Register/Vol. 70, No. 65 citing Beamesderfer et al. 2004; see CDFW 2015). Heublein et al. (2017) report the presence of gravid White Sturgeon females near potential spawning habitat on the Feather River during spawning season. However, we are unaware of documented successful egg deposition or recruitment from the Feather River watershed.

The absence of evidence for consistent spawning activity in the Central Valley outside of the Sacramento River and San Joaquin River mainstems may reflect a lack of recent systematic sampling in other Central Valley rivers. Although Moyle (2002) correctly surmised that White Sturgeon spawned in the San Joaquin River, evidence of successful spawning was not documented until 2011. Extensive levels of water development limit the frequency and spatial extent of successful SFE White Sturgeon spawning in the San Joaquin River (Jackson et al. 2016). Furthermore, low flow levels, construction and maintenance of the Stockton Deepwater Ship Channel, and high nutrient inputs to the San Joaquin River from agriculture upstream foster low dissolved oxygen conditions and frequent harmful algal blooms (e.g., of the toxic cyanobacteria *Microcystis*) (Berg and Sutula 2015) in the lower San Joaquin River, both of which are likely to impair SFE White Sturgeon migrations to and from spawning grounds in the San Joaquin River and its tributaries (CBDA & CV RWQCB 2006; CDFW 2015). The frequency of flow and temperature conditions suitable for SFE White Sturgeon spawning and incubation in the Feather River are likely to be far lower now than occurred historically, due to construction and operations of Oroville Dam and the Thermalito water management infrastructure (Heublein et al. 2017).

The geographic range of sub-adult and adult SFE White Sturgeon rearing in the estuary is also at risk of being severely constrained. According to Leidy (2007), SFE White Sturgeon were most abundant in Suisun and San Pablo Bays, and the western Delta, although they are also found in Central and South San Francisco Bay. However, because adult and sub-adult White Sturgeon are relatively sedentary, heavy fishing harvest and repeated fish kills after harmful algal blooms in San Pablo Bay threaten to eliminate SFE White Sturgeon in this area. Similarly, intense fishing pressure in the western Delta, and increasingly sophisticated fishing technology and communication among sport-anglers (CDFW 2023 at 55) may limit SFE White Sturgeon use of this area.

Figure 2: Current and historic distribution of White Sturgeon (Acipenser transmontanus) in California. The San Francisco Estuary (SFE) watershed is the only known spawning population in the state; detection of White Sturgeon in rivers north of the SFE is not believed to reflect presence of a current spawning population (CDFW 2015). California Fish and Game Commission (2023).

3.9. Changes in Abundance

SFE White Sturgeon briefly supported a commercial fishery before the turn of the 20th Century. Skinner (1962) reports estimated landings of White Sturgeon, although he acknowledges high uncertainty in these estimates due to variable record keeping (Figure 3). High harvest led to a population crash and, as a result, the commercial fishery was closed from 1901-1910. Records indicate much smaller landings in 1916 and 1917. The commercial fishery was closed by the state legislature after 1917 and all possession of White Sturgeon was prohibited until 1953. A recreational White Sturgeon fishery was opened in 1954 and continues to this day.

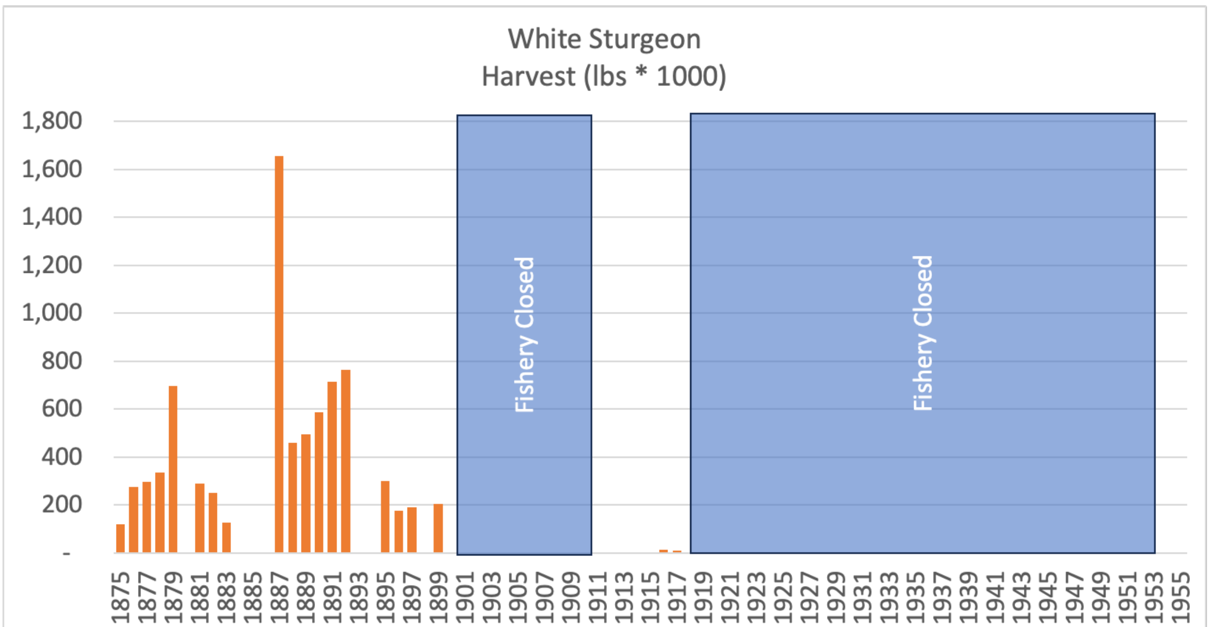


Figure 3 Commercial harvest of SFE White Sturgeon (in thousands of lbs). Data from Skinner 1962.

Several data sets reveal a decline in SFE White Sturgeon abundance over the past 25 years. For example, catches of Age 0 YOY White Sturgeon by the CDFW/Interagency Ecological Program's Bay Study reveal a decreasing trend in juvenile abundance over the past 40 years, punctuated by increases in years with high spring-summer freshwater flows out of the Delta and into San Francisco Bay (Figure 4; see Fish 2010).

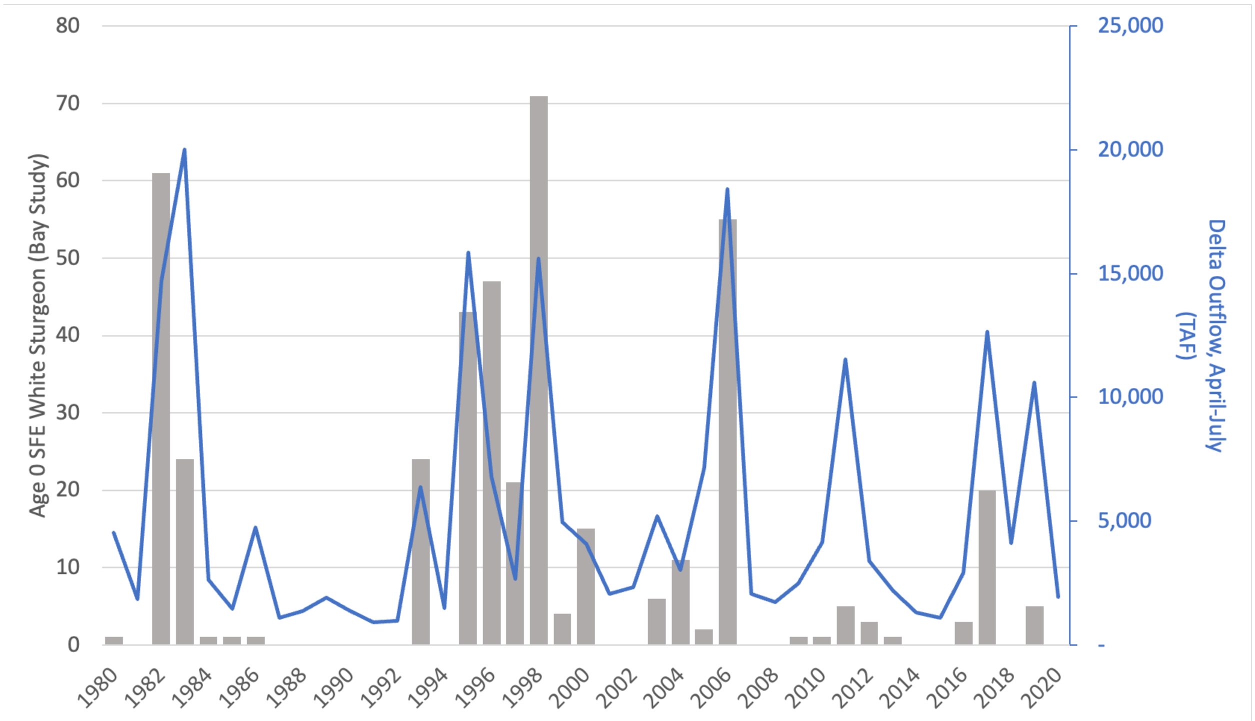


Figure 4: Relationship of spring-summer Delta outflow and SFE White Sturgeon juvenile recruitment. Left axis: Abundance index of Age 0 White Sturgeon caught in pelagic waters of the San Francisco Bay estuary (source: CDFW/Interagency Ecological Program's San Francisco Bay Study otter trawl). Right axis: Average Delta Outflow during April-July, in thousand acre-feet (source: Dayflow; https://data.cnra.ca.gov/dataset/dayflow). Abundance is strongly correlated with April-July Delta outflow (r=0.762, n=42). No index was generated in 2016.

Similarly, over the past 25 years, CDFW's mark-recapture studies of sub-adult and adult SFE White Sturgeon reveals a decline of approximately 80% (Figure 4). For such a long-lived species, a decline of this magnitude in less than three decades is concerning. CDFW's most recent estimate of the 5-year average of the harvestable (slot-sized) population (33,000 fish) (CDFW 2023) does not account for potentially massive losses to the SFE White Sturgeon population resulting from harmful algal blooms in 2022 and 2023. CDFW's Adult Sturgeon Study confirms a substantial decline in SFE White Sturgeon density from levels commonly observed in the latter half of the 20th century to those observed over the last decade (Figure 5); CDFW reports that, "2022 represented the most survey days with zero catch since the onset of [CDFW's Adult Sturgeon Study]" (California Fish and Game Commission 2023 at PDF p. 49).

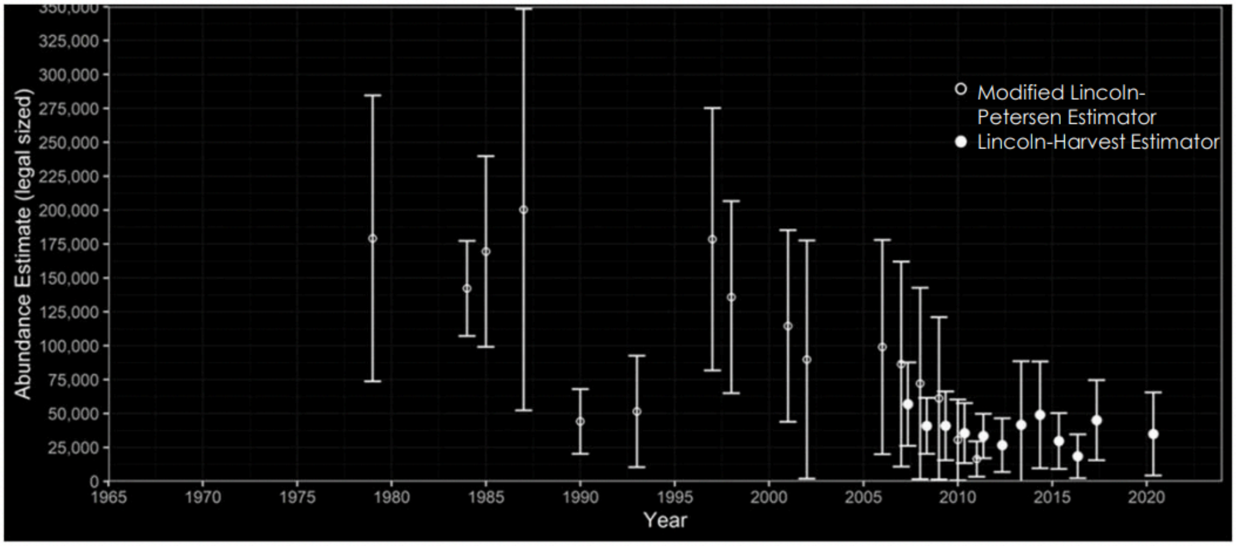


Figure 5: Estimated abundance of "slot-sized" SFE White Sturgeon based on CDFW mark-recapture studies. Whiskers represent error bounds. The latest year of data (2021) precedes fish kills related to harmful algal blooms in 2022 and 2023. CDFW 2023, slide 28.

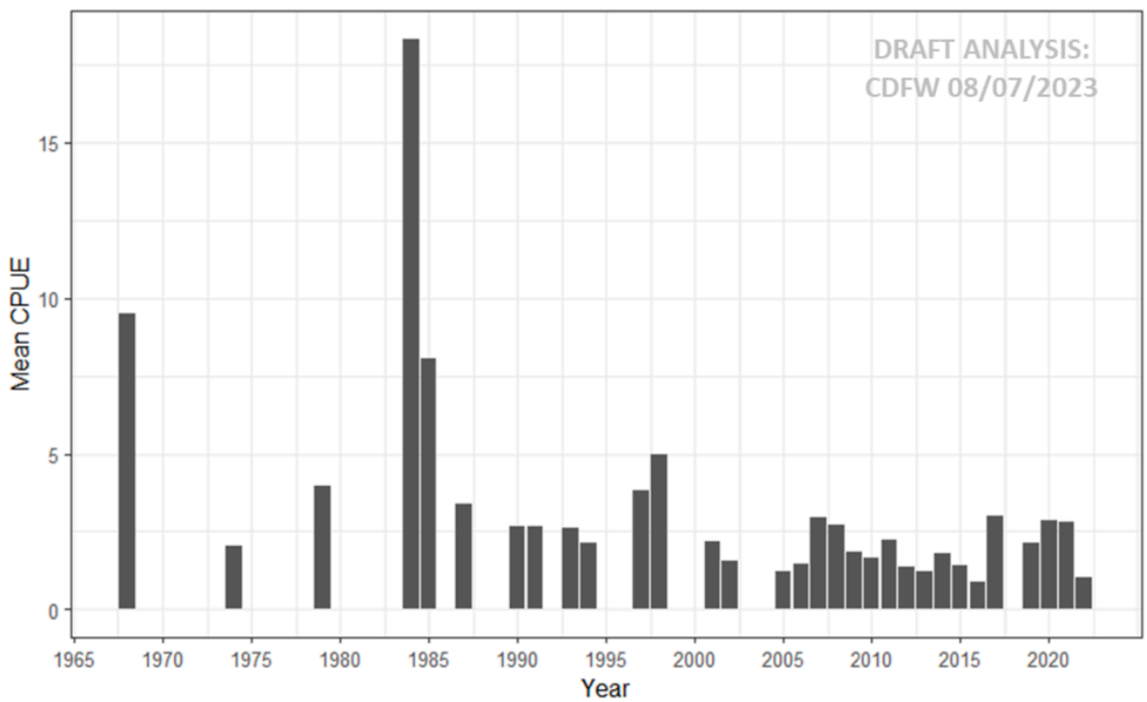


Figure 6: Catch-per-unit-effort (CPUE) of legal-sized White Sturgeon caught in the CDFW's Adult Sturgeon Study (trammel net gear) in the San Francisco Estuary, 1968 to 2022. Sampling was not conducted every year in the early decades of this sampling program; more recently, no sampling occurred in 2018 (Stompe and Hobbs 2023). A unit of effort is 100 net-fathom hours of fishing time. California Fish and Game Commission 2023 at Figure 9.

3.10. Population Trends

As described above, SFE White Sturgeon abundance is declining (Figures 4, 5, 6; CDFW 2015; SWRCB 2017; Blackburn et al. 2019; Schreier et al. 2022; Moyle and Rypel 2023; CDFW 2023; California Fish and Game Commission 2023). Blackburn et al. (2019 at p. 896) concluded that "Recent surveys suggest a declining population of White Sturgeon *Acipenser transmontanus* in the Sacramento–San Joaquin River basin (SSJ), California." Population trends are discussed below in the context of four factors for which data are available: the low frequency and declining magnitude of substantial juvenile recruitment related to Central Valley river flow conditions; high direct mortality related to entrainment and salvage at the massive water export facilities operated in the south Delta by the State Water Project (SWP) and the federal Central Valley Project (CVP); high rates of harvest in the recreational fishery; and catastrophic mortality in response to harmful algal blooms. Although these are not the only stressors on the SFE White Sturgeon population, they represent the largest negative anthropogenic effects on the population, and these are the impacts for which data are available to contextualize recent population trends.

3.10.1. River Flows and Delta Outflow

Recruitment of juvenile SFE White Sturgeon is flow-dependent. Chronically low river flows and reductions in freshwater inflow to San Francisco Bay (Delta outflow) resulting from water diversion and storage operations have been implicated in the decline of SFE White Sturgeon (CDFW 2015; Jackson et al. 2016; SWRCB 2017). As a result, successful cohort formation is infrequent for SFE White Sturgeon, corresponding to years of high spring-summer river flows into and out of the Delta (Figure 4; Moyle 2002; Fish 2010; CDFW 2015 citing Kohlhorst et al. 1991 and Schaffter and Kohlhorst 1999; SWRCB 2017). CDFW (2015 at p. 224) states "Annual recruitment of white sturgeon in California appears to have decreased since the early 1980s." Similarly, Blackburn et al. (2019 at pp. 897-898) observed that "Few age-0 and age-1 White Sturgeon have been sampled since 1998, and only two strong year-classes (2006 and 2011) have been documented in the last 19 years [through 2016]" and concluded that, "Continued poor recruitment has the potential to put the population at risk."

The SWRCB analyzed the relationship between average freshwater Delta outflow in March-July and recruitment of juvenile White Sturgeon (SWRCB 2017). The SWRCB found that recruitment of juvenile White Sturgeon did not occur when March-July average flows were below certain thresholds (see Figures 3.6-2 and 3.6-3 of SWRCB 2017 at pp. 3-65) and determined that monthly average Delta outflows > 37,000 cfs during this period were sufficiently protective of SFE White Sturgeon. From 1980-1999, average March-July Delta outflows >37,000 cfs occurred 30% of the time (6 out of 20 years). Since 1999, flows of this magnitude have occurred only 17.4% of the time (4 out of 23 years).

Using a similar analytical approach, we determined that recruitment of YOY White Sturgeon is very low or zero when Sacramento River flows ("SAC" + "YOLO" variables in Dayflow) average < 30,000 cfs between April and July (Figure 7).

Juvenile recruitment during optimal conditions may also be constrained by declines in the spawning stock of adults (SWRCB 2017 citing Gingras et al. 2014; Blackburn et al. 2019), adult fecundity, or both.

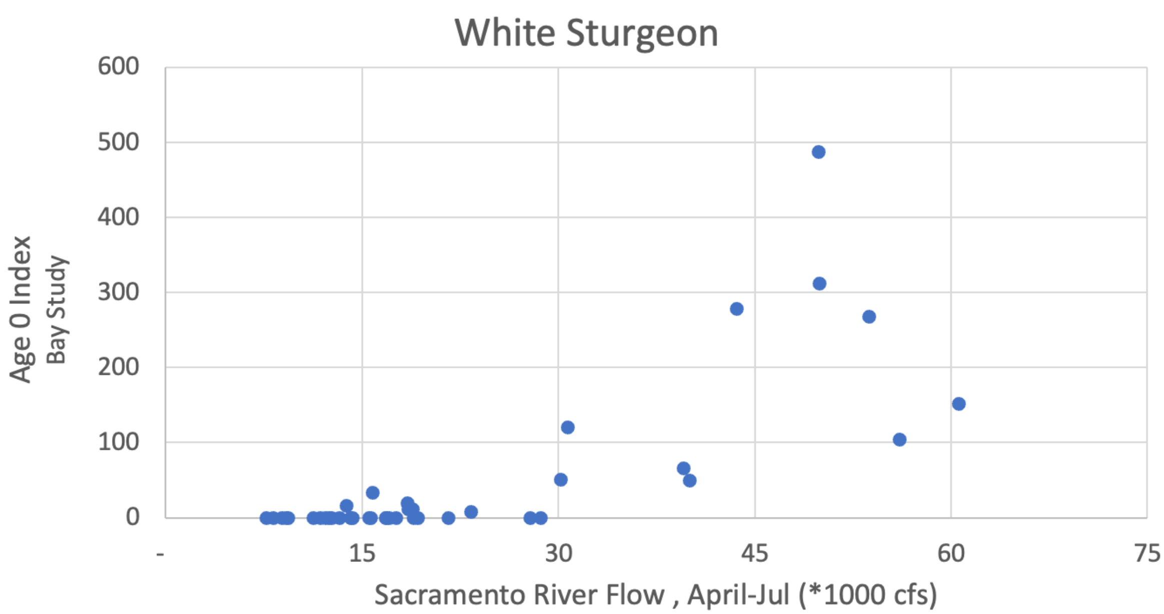


Figure 7: Relationship of spring-summer Sacramento River flow (= "SAC" + "YOLO" variables in Dayflow; https://data.cnra.ca.gov/dataset/dayflow) and an index of SFE White Sturgeon juvenile recruitment (source: Age 0 SFE White Sturgeon Index, CDFW//Interagency Ecological Program's Bay Study Otter Trawl). Age 0 abundance is strongly correlated with April-July Sacramento River flows (overall r=0.769, n=42, p<0.01).

3.10.2. Entrainment Mortality

Each year, fish "salvage" operations at the SWP and CVP South Delta water export facilities detect millions of fish that become entrained into the water export infrastructure (TBI 2012). Studies on survival of other fish species that become entrained show that orders of magnitude more fish are killed in the export facility infrastructure prior to salvage (e.g., by predation or unsuitable water quality conditions; Castillo et al. 2012). In other words, salvage is always much less than the total loss of fish attributable to exports, and failure to detect fish in salvage does not necessarily indicate that pre-screen mortality is zero.

Juvenile White Sturgeon are entrained episodically as a result of SWP and CVP water exports from the Delta. An unknown fraction of entrained White Sturgeon dies as a result of the entrainment and/or salvage process. Citing a study of entrainment mortality in the SFE's Green

Sturgeon population, Jackson et al. (2016 at p. 172) indicate that "Water diversions in the main stem [of the San Joaquin River] and throughout the San Francisco Estuary may also entrain biologically significant portions of annual juvenile production." During 2023 through October 6th, a combined total of 947 juvenile SFE White Sturgeon were salvaged at the CVP and SWP facilities in the south Delta – a new annual record (Figure 8). Given the relationship between salvage (fish enumerated at the fish screening facilities) and entrainment mortality (which includes fish eaten in the CVP and SWP diversion infrastructure upstream of the salvage facilities), total salvage of SFE White Sturgeon may underestimate mortality due to entrainment by 1-2 orders of magnitude.

Salvage may track annual recruitment of juveniles. To the extent this is true, trends in SFE White Sturgeon salvage data indicate a significant declining trend in abundance, including zero fish detected in 5 of the last ten years (Figure 8). High salvage mortality in 2023 likely reflects a relatively large cohort of YOY White Sturgeon produced following the record precipitation and runoff of that year. Results from 2023 illustrate how direct mortality related to entrainment may erode the capacity of the SFE White Sturgeon population to respond to environmental conditions that support successful reproduction.

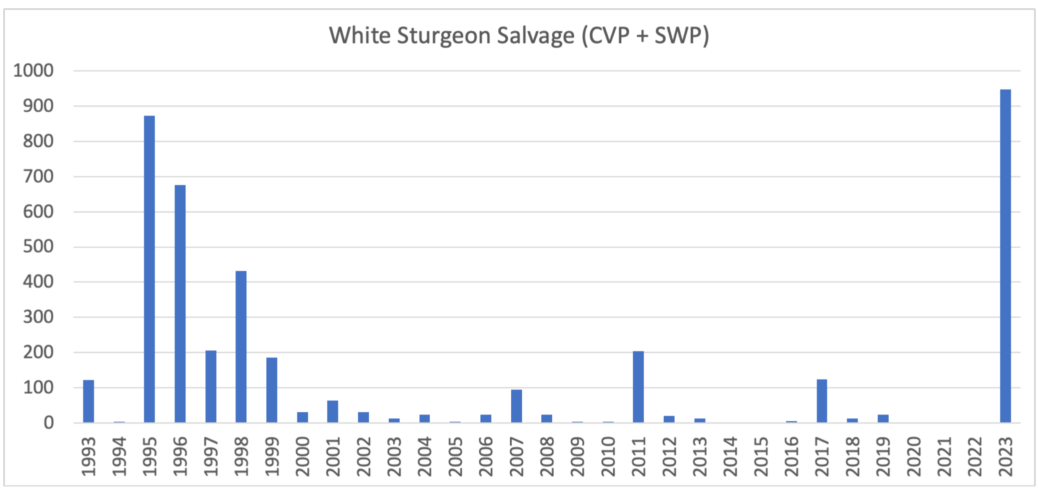


Figure 8: Annual combined salvage of White Sturgeon at Central Valley Project and State Water Project export operations (through 10/6/2023).

3.10.3. Fishing Harvest

California's sport fishery for SFE White Sturgeon has also been implicated in the decline of sub-adult and adult SFE White Sturgeon in the recent past. The SFE fishery targets White Sturgeon between 40 and 60 inches, which equates to fish between approximately 9 and 17 years of age. Anglers can catch 1 fish per day, and are limited to a harvest of three fish annually. Blackburn et al. (2019) estimated that the SFE sport fishery harvest rate between 2007 and 2015 averaged 13.6% (range: 8-29.6%). CDFW estimates that fishing exploitation rates from 2016 through 2021 averaged 8.1% (range: 3.5-14.2%; California Fish and Game Commission 2023 at PDF p. 22).

These harvest levels are far above those that the best available science indicates can be sustained (CDFW 2023). Blackburn et al. state (2019 at p. 896):

> "Under current conditions, the population will likely continue to decrease (population growth rate λ = 0.97); .... The models also suggested that White Sturgeon in the [SFE] could reach the replacement rate (i.e., λ ≥ 1.00) if total annual mortality for age-3 and older fish does not exceed 6%. Low levels of exploitation (i.e., <3%) would likely be required to maintain a stable population."

CDFW's mark-recapture abundance estimates of "slot sized" fish regularly exceeded 150,000 fish in the 1980s and returned to these levels in the late 1990s following an extended drought in 1987-1993 (Figure 5). By 2021, the estimated harvestable population had declined to a 5-year average of approximately 33,000 fish (CDFW 2023). This estimate does not account for the potential effect of massive fish kills in 2022 and additional mortality in 2023, related to red-tide blooms of the harmful algae, *Heterosigma akashiwo* (see below).

Population productivity is essential to fish population viability (McElhaney et al. 2000). Average population growth rates <1.0 clearly are not consistent with viability of SFE White Sturgeon. Moreover, Ulaski et al. (2022) found that existing harvest rates were inconsistent with population growth needed to attain federal targets for this species under the CVPIA.

3.10.4. Harmful Algal Blooms

In addition to the chronic drivers of declining abundance described above, the SFE White Sturgeon population is susceptible to widespread catastrophic loss from harmful algal blooms in the Bay and in the Delta. During July and August 2022, a red tide algal bloom, caused by the flagellated raphidophyte algae, *Heterosigma akashiwo*, spread across San Pablo, Central and South San Francisco Bays. *H. akashiwo* blooms have been linked to fish kills elsewhere in the world (CDFW 2023) and this bloom culminated in the rapid die-off of uncountable numbers of fish in the Bay (New York Times Aug. 30, 2022: https://www.nytimes.com/2022/08/30/us/fish-dead-algae-bloom-california.html) and at least one of its estuarine lagoons, (Lake Merritt, in Oakland California; Guardian Sept. 1, 2022; https://www.theguardian.com/us-news/2022/sep/01/dead-fish-oakland-lake-merritt-algae-bloom). White Sturgeon and Green Sturgeon suffered heavy mortality over a period of approximately one week. Based on reports and pictures submitted by volunteer naturalists and professional biologists, CDFW estimates 864 dead sturgeon were observed on the Bay shoreline, 195 of which were confirmed to be SFE White Sturgeon and 17 were confirmed as Green Sturgeon; the remaining carcasses were incomplete, poorly photographed, or were too badly decomposed to identify from pictures (CDFW 2023). Based on the ratio of confirmed carcasses (>90% of which were SFE White Sturgeon), it is clear that hundreds of SFE White Sturgeon carcasses were observed on the shoreline following the 2022 fish kill event. Another bloom of *H. akashiwo*, centered in San Pablo Bay (a sub-embayment in the larger San Francisco Bay complex), occurred in July of 2023. This bloom was shorter-lived and less extensive than the 2022 bloom. However, multiple observations of White Sturgeon carcasses were reported on the shoreline of San Pablo Bay in iNaturalist during the bloom and immediately after it receded (https://www.inaturalist.org/observations?nelat=38.86430003509466&nelng=-121.2081780273586&order_by=observed_on&place_id=any&subview=table&swlat=36.89297590683787&swlng=-123.6324969552935&taxon_id=49825). No official estimate of SFE White Sturgeon mortality in 2023 has been produced.

The number of SFE White Sturgeon carcasses observed on Bay Area beachlines during and immediately after the 2022 and 2023 red tide algal blooms likely represents a very small fraction of total mortality during the blooms as: (a) ~80% of the Bay's shoreline was not systematically scanned for sturgeon carcasses due to access restrictions, and (b) most dead sturgeon probably drifted to the bottom, were swept out of the bay by tides, or degraded before detection (Schreier et al. 2022; CDFW 2023 at slides 52-54). Although the true extent of SFE White Sturgeon mortality will never be known, adult mortality is highly likely to be at least an order of magnitude higher than the confirmed carcass counts. Precise comparisons of bloom-related mortality to the standing stock of White Sturgeon are not possible because of high uncertainty in existing estimates of both mortality and total abundance of adult and sub-adult SFE White Sturgeon.

4. Threats

Abundance of sub-adult and adult SFE White Sturgeon is at or near recorded lows (Figures 4, 5, 6). Successful cohort formation is rare (Jackson et al. 2016; Ulaski et al. 2022) and the size of successful cohorts appears to be decreasing (Figure 4; CDFW 2023), indicating declining population productivity. Both abundance and population productivity are likely to have declined further in response to massive fish kills caused by harmful algal blooms in 2022 and 2023; length data from confirmed SFE White Sturgeon killed in the 2022 event indicates that the majority of fish killed were of reproductive age (CDFW 2023). In addition, the population appears to have suffered significant range constriction caused by historic construction of impassable dams and their current operations; successful spawning in many rivers that likely supported spawning historically is unknown (e.g., the Stanislaus River, Tuolumne River) or extremely rare (Feather River, San Joaquin River). These low and/or declining levels of abundance, population productivity, and spatial distribution are not consistent with population viability (McElhany et al. 2000).

SFE White Sturgeon are imperiled primarily by:

- Central Valley water management infrastructure and operations, including:
  - the existence of several impassable Central Valley dams, which block access to former spawning and rearing grounds;
  - high levels of water diversion and the current operations of Central Valley dams, which collectively alter river hydrographs in ways that deprive SFE White Sturgeon of river and estuarine flows and water quality conditions necessary for successful recruitment;

  - direct mortality resulting from entrainment/salvage at CVP and SWP water export facilities in the south Delta;
- Overharvest in the recreational fishery; and
- Harmful algal blooms, some of which have resulted in direct mortality, and others (e.g., in the Delta) which routinely impair water quality conditions along the migration route for spawning White Sturgeon and their offspring.

Other threats include: low dissolved oxygen in the southern Delta; toxins, including selenium and mercury; and direct mortality from ship strikes and dredging. In addition to these existing threats, the risk of SFE White Sturgeon extirpation is exacerbated by imminent threats of direct and indirect habitat modification driven by human activities. Major existing and reasonably foreseeable imminent threats to the SFE White Sturgeon population are described below.

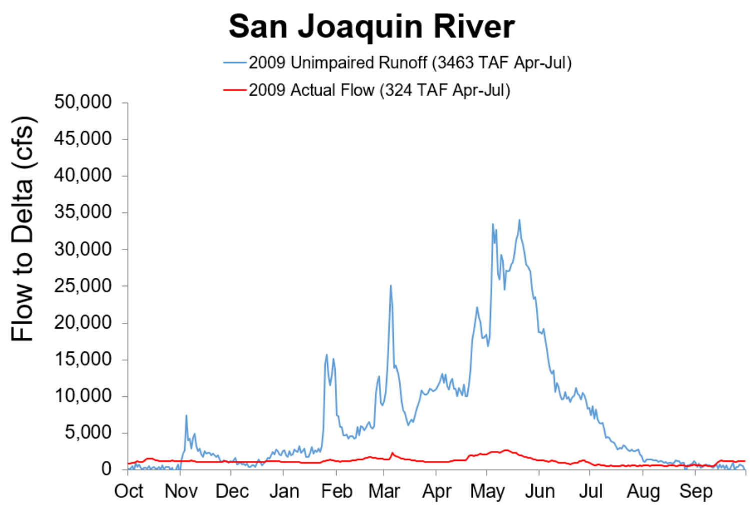
4.1. Modification or Curtailment of Habitat or Range

4.1.1. Dams

Impassable dams on each of the nine largest Central Valley tributaries block access to historic SFE White Sturgeon spawning habitat. Smaller, semi-passable dams below these "rim" dams likely impair access to otherwise accessible spawning habitats. In addition, dams block river sediment transport which impairs sturgeon spawning habitat and denies migrating larval and juvenile sturgeon turbidity (suspended sediment) that they use to hide from predators (CDFW 2015). Among major anthropogenic factors limiting, or potentially limiting, viability of populations of White Sturgeon in California, CDFW rates dams as "high" (CDFW 2015 see Table 1 at PDF p. 109).

4.1.2. Water Diversions

Radical alteration of the SFE hydrograph as a result of the large-scale capture and diversion of Central Valley runoff is a major force constraining SFE White Sturgeon productivity and driving declines in abundance (Moyle 2002; CDFW 2015, 2023; Jackson et al. 2016; SWRCB 2017; Blackburn et al. 2019; Ulaski et al. 2022; SWRCB 2017). Diversions and reservoir storage operations during wet years truncate peak river flows (Figure 9) and constrain the frequency of wet conditions upon which White Sturgeon cohort success relies. For example, between 1990-2018, 7 out of 11 of the years that Reis et al. (2019) classified as "wet" or "above normal" in terms of unimpaired Central Valley runoff were actually "below normal" or drier in terms of water that flowed out of the Delta (Figure 10). Thus, water diversion and storage reduce the frequency and quality of conditions that favor SFE White Sturgeon recruitment.



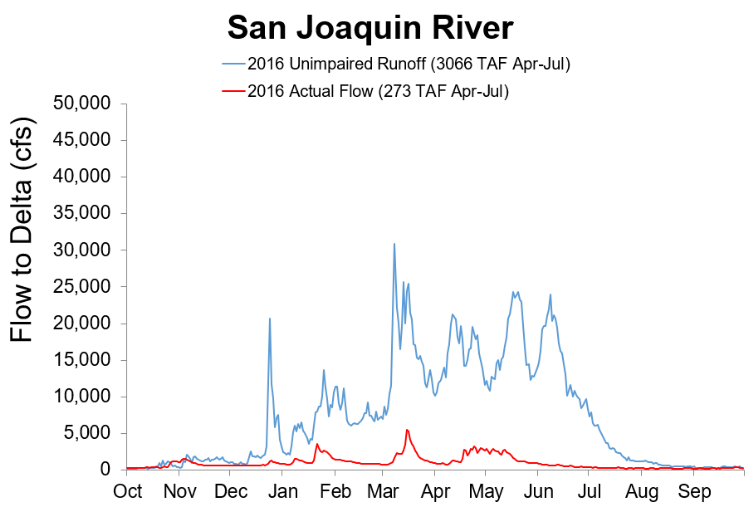


Figure 9: Unimpaired hydrograph (blue lines) vs. actual hydrograph (red lines) for the San Joaquin River in 2009 (top) and 2016 (bottom). Water diversions and reservoir operations eliminate high flow conditions that correspond with successful White Sturgeon recruitment on this and other Central Valley rivers.

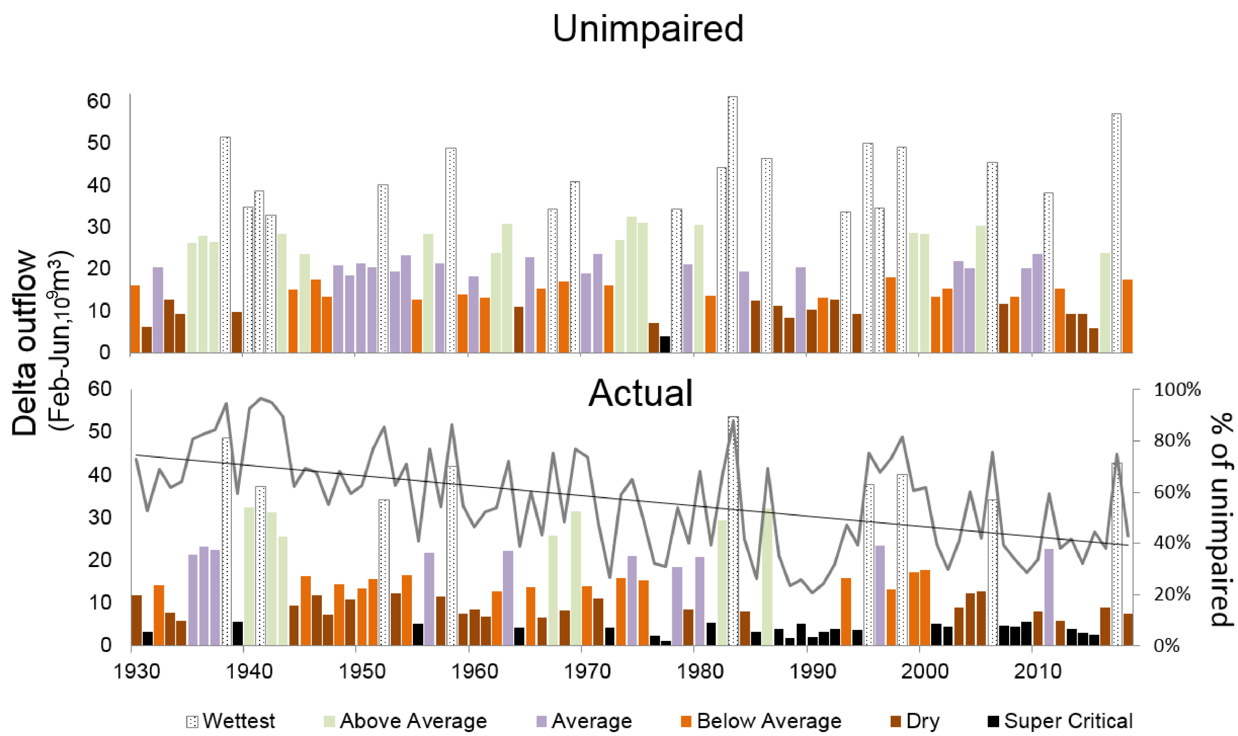


Figure 10: Trends in actual Delta outflow (below) relative to Central Valley unimpaired runoff (above). Coloring of bars represent water year types based on quintiles of unimpaired flow from 1922-2016. In terms of actual Delta outflow, the frequency of "wet" and "above normal" years is markedly reduced compared to unimpaired hydrology. The percentage of unimpaired flow reaching San Francisco Bay (line in lower panel; right y-axis) declined significantly during this time-period (Kendall's tau = −0.36, $p < 0.001$), including since 1995 (Kendall's tau = −0.29, $p < 0.05$). Reis et al. 2019.

Despite the fact that current regulations are clearly inadequate to maintain freshwater flow or water quality conditions necessary to maintain viable populations of several fishes native to San Francisco Bay, the Delta, and their tributary rivers (SWRCB 2010, 2017; CDFW 2010; USFWS 2022), recent changes to state and federal ESA regulations nevertheless allow for increased water diversion, decreased river flows, and reduced Delta outflow as compared to earlier regulations (see, e.g., Figure 5.16-13, at p. 5-373 in Reclamation 2019; see, e.g., Tables 5.2.3-5.2.4 in CDWR 2020 at p. 5-12). Moreover, several recent proposals for new water management infrastructure described below seek to increase water diversions, particularly during wetter periods when high river flows and Delta outflows would otherwise benefit SFE White Sturgeon reproduction and recruitment.

Decreased freshwater flows through the watershed currently pose a severe, chronic threat to SFE White Sturgeon viability. Current management of river and estuarine flows (i.e., regulation of reservoir operations and diversions) constrains the productivity of the population and promotes gradual, but persistent decline in the population. Freshwater flow conditions are likely to be further degraded by multiple pending projects that would divert and store yet more runoff in the Sacramento Valley and the Delta.

4.1.3. Sites Reservoir

This proposed new off-channel reservoir would divert water from the Sacramento River during high flow periods from October-June, for later delivery to agricultural and urban users. If approved, Sites Reservoir diversion operations are expected to reduce April-June flows, especially under wet conditions, in the known spawning, rearing, and migration corridor of SFE White Sturgeon in the Sacramento River (e.g., Sites RDEIR/SDEIS Table 5c-9-1c). This is likely to have a negative effect on successful spawning and recruitment of juvenile SFE White Sturgeon.

4.1.4. Delta Conveyance

The California Department of Water Resources has proposed a new diversion from the Sacramento River that would route Sacramento River flow through an underground tunnel to existing export infrastructure in the southern Delta ("the Delta Conveyance Project"). Operation of the Delta Conveyance Project would substantially *reduce* flows in the lower Sacramento River, particularly during spring-summer months of wetter years (Delta Conveyance Project, Draft EIR (CDWR 2022) Appendix 05C Table 5C-42 at p. 5c-43); https://www.deltaconveyanceproject.com/planning-processes/california-environmental-quality-act/draft-eir/draft-eir-document) that would otherwise support SFE White Sturgeon reproduction and recruitment.

4.1.5. Bay-Delta Water Quality Control Plan Update and Proposed Voluntary Agreements

The SWRCB's existing Bay-Delta Water Quality Control Plan and related regulations are inadequate to protect native fishes, even when supplemented by flow and diversion constraints applied under the federal and state ESAs (SWRCB 2010, 2017; CDFW 2010; USFWS 2022). The current water quality standards governing flow into the Delta from the Sacramento River watershed, through the Delta, and into San Francisco Bay, were adopted in 1995.

The SWRCB recently proposed new draft standards for flow from the Sacramento River watershed into the Delta, in-Delta hydrodynamics, and Delta outflow (SWRCB 2023). The "proposed project" would require a minimum of 55% of unimpaired flow from the Sacramento River and the Delta's eastern tributaries to reach the Delta year-round and for that volume to become Delta outflow. However, the "proposed project" will not achieve the frequency and magnitude of flow conditions that SFE White Sturgeon need to sustain their populations and fully recover. For example, the SWRCB has determined that average March-July Delta outflows ≥ 37,000 cfs are protective of SFE White Sturgeon (SWRCB 2017 at pp. 3-63 through 3-66). The SWRCB's modeling predicts that flows of this magnitude will occur with only marginally higher frequency than baseline (19% vs. 15%) under the SWRCB's proposed project (SWRCB 2023 Table

7.6.2-5 at p. 7.6.2-38). Moreover, this marginal difference in frequency of suitable flows is entirely due to flows that exceed *current* diversion and storage capacity (i.e., unregulated flows), but which would be available for capture and storage by new diversions (e.g., the proposed new Delta Conveyance Project) and/or new storage facilities, such as the proposed Sites Reservoir Project (see SWRCB 2017 at p. 5-31, showing that without "unregulated flows," Delta Outflow targets for White Sturgeon and Green Sturgeon would be achieved less frequently than baseline – 12% vs. 15%). Notably, the SWRCB's "high flow" alternative (65% of unimpaired Sacramento River and east side tributary inflow to the Delta) is projected to result in Delta outflows greater than or equal to the SWRCB's White Sturgeon minimum flow threshold in 24% of years (SWRCB 2023 Table 7.6.2-5 at p. 7.6.2-38), approximately the frequency needed to ensure spawning opportunities necessary to sustain and recover the SFE White Sturgeon population (1 in 4 years, see above).

The SWRCB also described proposed Voluntary Agreements (VAs) as an alternative to its "proposed project." These VAs would provide far less flow into San Francisco Bay, through the Delta, and in tributary rivers where SFE White Sturgeon spawn and rear, than the SWRCB's proposed project. In fact, during years with "wet" hydrology, modeling indicates that the Voluntary Agreements would result in *less flow* than under baseline conditions (see, e.g., SWRCB 2023 at Table 4-13; and Table G3a-10). Thus, the VA alternative threatens to significantly *diminish* the frequency and magnitude of river and Delta outflow conditions that White Sturgeon rely on for successful spawning and juvenile recruitment.

4.1.6. Entrainment Mortality

Direct and indirect mortality related to SWP and CVP operations in the southern Delta are a subset of overall water management impacts on the SFE White Sturgeon population. However, since these operations result in substantial direct mortality in years of high sturgeon recruitment, we consider this issue separately here. Although there is no known conversion for estimating total White Sturgeon entrainment mortality as a function of salvage of these fish (as there is for other species, e.g., Castillo et al. 2012), it is clear that: (a) there is no reason to expect high survival of salvaged fish, (b) total mortality will be greater than the number of fish enumerated in salvage because of losses prior to the fish screens, and (c) salvage has been episodically high (Figure 8).

Whereas constraints on export operations contained in the 2008/2009 federal ESA biological opinions for Delta Smelt and anadromous fishes have been found to reduce salvage and related mortality of certain protected species (e.g., Delta Smelt; Smith et al. 2021), there is no reason to believe that those constraints are adequate to protect White Sturgeon, which are vulnerable in different seasons and under different hydrological conditions than other imperiled species. Furthermore, the export constraints detailed in the 2008/2009 biological opinion have been altered and may be altered again during the ongoing ESA reconsultation on CVP operations. Specifically, the most recent federal biological opinion and CESA Incidental Take Permit allow for much higher levels of export during "storm" conditions (CDFW 2020 at p. 92). If juvenile SFE White Sturgeon capitalize on high-flow storm events to disperse in the Delta, then implementation of this “storm-flex” provision would be expected to increase entrainment mortality.

4.2. Overutilization for Recreational Purposes

4.2.1. Recreational Harvest

White Sturgeon life-history and behavior make the SFE White Sturgeon population susceptible to overharvest. White Sturgeon exhibit delayed maturation and do not spawn every year; thus, loss of older, more fecund, adult females represents a significant blow to overall SFE White Sturgeon population productivity (Blackburn et al. 2019). These same life history attributes can mask long-term declines in the population (Ulaski et al. 2022). Legal recreational fishing for SFE White Sturgeon has exacerbated recent population declines (Blackburn et al. 2019; CDFW 2023). CDFW’s planned response – to set harvest levels to 4% of the harvestable population – will not eliminate the threat to the population posed by recreational fishing.

In addition, because adult and sub-adult White Sturgeon tend to aggregate in a small area for extended periods (Hildebrand et al. 2016), fishing boats can concentrate angling pressure on significant population pockets. This threat to the population from legal harvest is exacerbated by the expansion of tools for rapid communication in the field (cell phones; social media) that allow recreational anglers and boat captains to quickly learn about and move towards areas of high catches. In addition, White Sturgeon predictably return to favored spots seasonally (Hildebrand et al. 2016), making them easy for fishing boats to find and target.

In response to extremely high harvest rates in the recent past, CDFW has proposed to develop new fishing regulations intended to achieve a 4% harvest mortality rate (California Fish and Game Commission 2023). This target is significantly above the levels Blackburn et al. (2019) calculated would be necessary to maintain a *stable* population (<3%); harvest rates consistent with SFE White Sturgeon population growth would be lower still. And Blackburn’s calculations did not account for the emerging threat of harmful algae blooms, which resulted in extreme SFE White Sturgeon mortality events in 2022 and 2023.

Recreational fishing is a grave threat to SFE White Sturgeon in the near-term. At current harvest levels, the threat from sportfishing is severe. It is possible that new proposed restrictions will reduce the near-term impacts from recreational fishing, but the best available science indicates that, unless harvest rates are restricted to <3% of the population, the population will continue to decline (Blackburn et al. 2019) and will certainly not recover.

4.2.2. Poaching

Poaching SFE White Sturgeon, principally for their eggs (caviar), has been identified as a threat to the population (Israel et al. 2009). Organized poaching rings have been identified and participants arrested, but there are no data on the current magnitude of this problem.

4.3. Inadequacy of Existing Regulatory Mechanisms

Existing regulatory mechanisms are clearly inadequate to protect SFE White Sturgeon from further decline and eventual extirpation.

4.3.1. Water Diversion Regulations

Despite the existence of regulations addressing water diversions under the state and federal Clean Water Acts (i.e., the Bay-Delta Water Quality Control Plan) and state and federal ESAs (i.e., state CESA Incidental Take Permit and federal Biological Opinions), the proportion of Central Valley-wide unimpaired runoff that makes it through the Delta to San Francisco Bay has declined dramatically over the past century and over the past 25 years (Figure 10; Hutton et al. 2017; Reis et al. 2019). Moreover, existing river and estuarine flow requirements are minimum standards that do not address and will not prevent the further reduction of "surplus" (i.e., unregulated) flows by proposed projects in the near future. As SWRCB (2023, at 1-9) explains:

> "Total average annual unimpaired (without diversions and dams under current channel and infrastructure conditions) outflows from the Bay-Delta watershed are about 28.5 million acre-feet (MAF). Annual average outflows with diversions are a little more than half this amount at about 15.5 MAF, and outflows during the winter and spring from January through June are less than half. However, average regulatory minimum Delta outflows are only about 5 MAF, or about a third of current average outflows and less than 20 percent of average unimpaired outflows. Existing regulatory minimum Delta outflows would not be protective of the ecosystem, and without additional instream flow protections, existing flows may be reduced in the future, particularly with climate change and additional water development absent additional minimum instream flow requirements that ensure flows are preserved in stream when needed for the reasonable protection of fish and wildlife." (emphasis added).

Several other recent reviews have similarly concluded that minimum flow requirements and current flow levels in the SFE watershed are inadequate to protect endangered fishes or recreational and commercial fisheries (SWRCB 2010, 2017; CDFW 2010; USFWS 2022). The effect of water diversion and reservoir storage operations on the volume and timing of flows to San Francisco Bay can be seen in the reduced frequency of years with high spring-summer river flows, relative to the frequency of naturally occurring wet conditions (Figure 10). Thus, current water management practices reduce the frequency of conditions that SFE White Sturgeon depend on for successful spawning and larval rearing. Moreover, as described above, adoption of currently proposed updates to the Bay-Delta Water Quality Control Plan (SWRCB 2023), Sites Reservoir, and the Delta Conveyance Project would each reduce the frequency and magnitude of high spring-summer Delta inflows and outflows, and would therefore reduce the frequency and magnitude of successful SFE White Sturgeon recruitment.

4.3.2. Recreational Fishing Regulations

CDFW acknowledges that increased regulation of fishing harvest will be needed to stabilize the population (CDFW 2023; California Fish and Game Commission 2023). CDFW has convened agency and outside experts to review potential changes in fishing regulations aimed at attaining a new maximum exploitation rate target of 4% (California Fish and Game Commission 2023 at PDF p. 25). This target level of harvest is substantially higher than the maximum Blackburn et al. (2019) calculated would be necessary to maintain a stable population (<3%) – that calculation was made prior to the emergence of harmful algal blooms and associated fish kills in San Francisco Bay-proper. CDFW's revised harvest target would not be expected to halt declining abundance of SFE White Sturgeon, much less restore this population.

Separately, CDFW staff proposed emergency fishing regulations that would restrict the SFE White Sturgeon fishery to catch-and-release only for the 2024 fishing season. However, at its October 11, 2023, public meeting, the California Fish and Game Commission rejected this proposal in favor of a series of temporary modifications to fishing regulations aimed at achieving a harvest mortality target that was estimated, without supporting evidence, to be "4-5%." Thus, there are no current plans to reduce SFE White Sturgeon harvest to levels consistent with maintaining a stable, much less recovering, population.

4.3.3. Nutrient Enrichment Regulations

Nutrient enrichment of San Francisco Bay and its main tributaries supports increasingly common and widespread harmful algal blooms that kill SFE White Sturgeon and limit its geographic range. But current regulation of nutrient loads from agricultural runoff, treated municipal wastewater, and refinery effluent have not prevented the SFE from becoming one of the most nutrient-enriched estuaries in the world (Cloern et al. 2020). Until nutrient loading into the Bay (primarily by local wastewater treatment plants) is significantly reduced, widespread blooms are likely to recur in the pelagic waters of the Bay. Although the Regional Board anticipates requiring load reductions in an updated wastewater nutrient permit, changes in infrastructure and operations required to substantially reduce nutrient loads are likely to take many years to implement. Therefore, it is highly likely that SFE White Sturgeon will continue to suffer loss of habitat and potentially catastrophic fish kills for the foreseeable future as a result of harmful algal blooms.

In the Delta, river flows are chronically impaired (SWRCB 2017; Reis et al. 2019). Although the SWRCB has been reviewing water quality (flow) standards for the Bay-Delta since 2009, and adopted new standards for San Joaquin River flow in 2018, river and estuarine flows are still being managed to meet the requirements adopted nearly thirty years ago, in 1995. As a result, residence times in the southern Delta support widespread seasonal toxic algal blooms in all but the wettest years. Indeed, the state is contemplating replacing the unimplemented 2018 San Joaquin River basin flow standards (which would require that 40% of unimpaired flow from the lower San Joaquin River's three main tributaries reach the Delta) as part of a "voluntary agreement" with water diverters on the Tuolumne River (SWRCB 2023) – the proposed VA would provide significantly less flow in the Tuolumne River and San Joaquin River than the 2018 standards would provide. It is also not clear whether even the 2018 standards would result in flows needed to mitigate harmful algal blooms during the July-September period, when no new flow standard applies.

4.4. Other Natural or Manmade Factors Affecting Continued Existence

4.4.1. Harmful Algal Blooms

As described above, harmful red tide (*H. akashiwo*) algal blooms in San Francisco Bay led to substantial die-off of SFE White Sturgeon in 2022 and 2023 (CDFW 2023; California Fish and Game Commission 2023). These widespread blooms, and more localized persistent blooms of cyanobacteria (*Microcystis*) in the San Joaquin River migration corridor, also threaten to constrain the geographic extent of SFE White Sturgeon spawning and rearing. Bloom formation corresponds to high light penetration, water temperatures, nitrogen (N) and phosphorus (P) (collectively, "nutrient") concentrations, and residence times. In the Bay, the one factor under human control is nutrient concentrations. In the Delta, because technologies to reduce N loads in treated wastewater effluent have been implemented at the Stockton and Sacramento wastewater treatment plants, reducing residence time with increased river flows (especially in the San Joaquin) represents the main viable strategy to mitigating or preventing harmful algal blooms.

Repeated red-tide algal blooms, in 2022 and again in 2023, indicate that sizeable SFE White Sturgeon mortality events may occur more frequently in the future. Indeed, future blooms may be worse. The SFE is highly susceptible to harmful algae blooms because it is chronically over-enriched in N and P compounds that fuel phytoplankton growth and reproduction (Cloern et al. 2020). *H. akashiwo* forms cysts that lay dormant in bottom sediments; the 2022 bloom may have deposited these cysts over a large portion of San Francisco Bay, setting the stage for rapid development of widespread blooms in the future. Moreover, *H. akashiwo* is not the only potentially harmful, bloom-forming phytoplankton in the Bay; the San Francisco Bay Regional Water Quality Board's (Regional Board) Nutrient Management Strategy identifies 17 harmful algal bloom-forming species in the SFE, and some of these are more toxic than *H. akashiwo* (SFEI 2016). Whereas, the Regional Board anticipates proposing regulations that would constrain nutrient loading of the Bay from wastewater treatment plants (Eileen White, Executive Director of the San Francisco Bay Regional Water Quality Board, pers. comm., Aug. 7, 2023), no reduction in nutrient loads has yet been required and such regulations (if adopted) are not likely to result in attainment of targeted nutrient load reductions for at least 10 years. Thus, the harmful algal blooms are an increasingly imminent threat to the SFE White Sturgeon.

In addition, harmful blooms of highly toxic cyanobacteria in the genus *Microcystis* are increasingly common on the lower San Joaquin River during the spring and summer (Kudela et al. 2023), including months when adult and juvenile SFE White Sturgeon would be migrating to and from the San Joaquin River and its tributaries. These blooms and related low dissolved oxygen levels in the Stockton Deepwater Ship Channel likely form a barrier to migrating SFE White Sturgeon adults and juveniles (CBDA & CVRWQCB 2006; CDFW 2015 at p. 108).

Harmful algal blooms pose a potentially catastrophic, immediate threat to SFE White Sturgeon. Given the combination of excessive nutrient loading, increased water diversions, and climate change, it is likely harmful algal blooms will occur with increased frequency and severity, leading to future fish kills and impairment of migrations.

4.4.2. Pollution

As Gunderson et al. (2017 at p. 334) note: "[t]he San Francisco Estuary is heavily influenced by anthropogenic activities, including historic and chronic contaminant inputs. These contaminants can adversely affect SFE fish populations, particularly white sturgeon, because they are a benthic dwelling, long-lived species." SFE White Sturgeon are sensitive to agricultural and industrial pollutants, many of which bioaccumulate, leading to deformities, slower growth, and reduced reproductive potential (CDFW 2015 at p. 230). Their exposure to organochlorine pesticides, mercury, and selenium is quite high in the SFE. Indeed, Gunderson et al. (2017) found elevated concentrations of several metals, as well as DDE, PCBs, PBDEs, galaxolide, and selenium in the tissues of SFE White Sturgeon. Given this fish's long lifespan, PCB's and other pollutants may represent a significant population-level concern (Moyle 2002; CDFW 2015 and sources cited therein).

The threat to SFE White Sturgeon posed by selenium accumulation may be underappreciated. Elevated levels of selenium (Se) lead to decreased swimming activity, slower growth, lower energy reserves, and decreased survival in SFE White Sturgeon (CDFW 2015 at p. 230). Se enters the SFE from agricultural runoff and stormwater discharge – particularly from naturally seleniferous soils on the west side of the San Joaquin Valley – and from petroleum refinery effluent in Suisun Bay and San Pablo Bay. Gunderson et al. (2017 at p. 335) report Se levels in SFE White Sturgeon consistent with those associated with impaired reproductive success. Stewart et al. (2020) reported Se in tissues of Sacramento Splittail taken from Pacheco Creek, which receives effluent from three nearby oil refineries, that were higher than those from Splittail sampled elsewhere in the SFE. These results suggested that "…the proposed EPA Se criteria for muscle tissue in Splittail may be under-protective." (Stewart et al. 2020 abstract). White Sturgeon also inhabit the receiving waters of Pacheco Creek and forage on some of the same prey as Sacramento Splittail (e.g., mollusks) as well as the Splittail themselves, suggesting that SFE White Sturgeon exposure to refinery-origin Se may be higher than previously understood.

4.4.3. Climate Change

The regional effects of global climate change are likely to exacerbate several stresses on the SFE White Sturgeon population. Potential effects include increases in water temperature that would impair reproductive success; increased developmental rates leading to potential mismatch between life-history transitions and prey availability; disease susceptibility; and increased duration, intensity, and extent of harmful algal blooms (CDFW 2015). Anthropogenic impacts to climate have increased the risk of persistent droughts in California (Diffenbaugh 2015); alterations to annual and seasonal hydrology resulting from climate change are also likely to further impair SFE White Sturgeon recruitment.

4.4.4. Hatcheries

Hatchery supplementation of wild sturgeon is not currently a threat to the SFE White Sturgeon population, though it has been proposed. CDFW (2015 at p. 233) reports that artificially reared sturgeon were outplanted from 1980-1988. Hatchery supplementation could threaten SFE White Sturgeon discreteness or the DPS's significance to the species as a whole. Conservation status assessments for Pacific salmon include thresholds for hatchery influence (Lindley et al. 2007). Indeed, Central Valley fall-run and late-fall run Chinook Salmon populations are listed as California Species of Special Concern, in part, because of high levels of hatchery influence (CDFW: https://wildlife.ca.gov/Conservation/Fishes/Chinook-Salmon). Furthermore, hatchery-rearing of SFE White Sturgeon would not alleviate major threats to the population (e.g., overharvest, harmful algae blooms, selenium toxicity) as these threats affect mainly older fish; hatchery-rearing would not undo or mitigate several factors that imperil the population in the first place.

4.4.5. Ship Strikes

White Sturgeon are killed by strikes from boat and ship hulls or propellers (Hildebrand et al. 2016; Demetras et al. 2020). The population level impact of this effect is unknown. There is concern that narrow sections of the SFE (e.g., Carquinez Strait) may funnel high vessel traffic into the migratory path of SFE White Sturgeon on their way to and from spawning grounds, leading to deadly boat strikes (A. Schreier, UC Davis, pers. comm, Oct. 31, 2023). As the adult spawning stock becomes more limited, the potential for consistent loss of large females to ship strikes could become problematic (CDFW 2015).

4.4.6. Dredging

Dredging of the federal navigational channels, as well as smaller-scale dredging projects, poses a variety of direct and indirect impacts to SFE White Sturgeon. In 2009, the San Francisco Estuary Institute prepared a study for the U.S. Army Corps of Engineers regarding SFE dredging impacts on green sturgeon (Stanford et al. 2009). Direct impacts include entrainment from hydraulic dredging, exposure to contaminated sediments, water quality impacts via sediment resuspension and sedimentation, disturbance from underwater noise, and changes to habitat (e.g., bed leveling). Indirect impacts include modifications to prey base, increased occurrence of ship propeller strikes, and predation by invasive species. Impacts to Green Sturgeon are likely amplified for SFE White Sturgeon, because SFE White Sturgeon spend most of their lives in the SFE, whereas Green Sturgeon migrate through the estuary quickly.

5. Criteria for Listing as a Distinct Population Segment

As discussed below, the SFE population of White Sturgeon clearly meet the criteria for a distinct population segment (DPS) of the larger species and should be listed as a threatened.

5.1.1. Discreteness

The SFE White Sturgeon population is markedly separated from other populations of this species. The nearest breeding population is in the Columbia River estuary, over 700 miles away. By comparison, even though Green Sturgeon are much more likely than White Sturgeon to migrate in marine environments, the southern Green Sturgeon DPS (San Francisco Bay population) is considered to be markedly separated from other such populations found as nearby as southern Oregon (Rogue, Umpqua, and Klamath Rivers; 17388 Federal Register/Vol. 70, No. 65). Thus, the great distance between the SFE population of White Sturgeon and the nearest other extant breeding population represents marked geographical separation.

In addition, genetic data indicate separation between the SFE population and other White Sturgeon spawning populations, though differences are not as dramatic as those seen in the isolated Kootenai River population (Drauch Schreier et al. 2013; Willis et al. 2022). CDFW (2023 at slide 8) states that the "California population [of White Sturgeon] is genetically distinct from other west coast populations". White Sturgeon intra-specific population genetic structure appears to reflect the relative geographic proximity and isolation of populations. Source assignment based on genetic characteristics was more accurate for the Sacramento River than in any source population other than the geographically isolated upper Snake River and Kootenai River populations (*see* Table 2 of Willis et al. 2022). Principle component analysis of genetic data revealed distinctive variation in the SFE White Sturgeon population. This population represented one extreme of the main axis of genetic variation, though inter-population genetic variation overlapped with the lower Columbia River Estuary population to a limited extent (*see* Figure 3 of Willis et al. 2022). Similarly, Drauch Schreier et al. (2013) found more private alleles (18) in the SFE population of White Sturgeon than in other populations they sampled; private allele frequency was the second highest among source populations when corrected for sample size (the lower Fraser River population had the highest frequency of private alleles). Hildebrand et al. (2016 at p. 264) treated White Sturgeon in the SFE as a separate population for geographic and management reasons and succinctly summarized genetic analyses of population structure as follows:

> "Several investigations have revealed population genetic structuring among the Sacramento-San Joaquin Bay-Delta, Columbia, and Fraser River systems. Early studies identified significant differences between these river systems in allozyme allele or mtDNA haplotype frequencies (Bartley et al., 1985; Brown et al., 1992a,b, 1993) ... More recent studies using polysomic microsatellite markers confirm the presence of genetic substructure among river basins. Rodzen et al. (2004) genotyped 670 WS from the Sacramento-San Joaquin Bay-Delta, Columbia, and Fraser River basins and reported a global FST value, a measure of among population genetic differentiation, of 0.19 which suggests a moderate amount of genetic divergence exists among basins. A more comprehensive survey of WS population structure that included samples collected throughout the species distribution identified six distinct populations among basins: the Sacramento-San Joaquin Bay-Delta [SFE], lower Columbia, middle Snake, Kootenai, lower Fraser (below Hells Gate), and upper Fraser (above Hells Gate; Drauch Schreier et al., 2013)."

5.1.2. Significance

The SFE White Sturgeon population is biologically and ecologically significant to the species as a whole. The SFE represents the southernmost breeding population of White Sturgeon. The SFE's setting as the largest inland estuary on the Pacific Coast of the Americas is unique for White Sturgeon populations. Here, the White Sturgeon population is exposed to a biological assemblage and to variation in temperature, ocean currents, and estuarine dynamics that are unique in the species' range. Therefore, this discrete population occurs in an unusual and unique ecological setting relative to conspecific populations. Furthermore, loss of the SFE White Sturgeon population would clearly represent a very significant gap in the species' geographic range, substantially reducing the historic range of this fish along the Pacific Coast of the lower 48 United States (Figure 1).

The distinctively rapid somatic growth of SFE White Sturgeon relative to populations elsewhere (see above) also indicates that this population is responding to ecological conditions in the SFE that are unique across the species' range. Alternatively, it is possible that somatic growth differences are caused by underlying genetic differences in addition to, or instead of, ecological differences. Regardless of their underlying cause, high growth rates of SFE White Sturgeon point to the evolutionary significance of this distinct population.

Genetic characteristics of the SFE White Sturgeon DPS differ from other populations in the species' range. Drauch Schreier et al. (2013) found eighteen alleles unique to SFE population of White Sturgeon; this was the second highest frequency of private alleles among populations studied, after corrections were made for sample size. Willis et al. (2022) demonstrated that this population formed one extreme of the main axis of genetic variation for this species. Furthermore, the SFE White Sturgeon population displays several unique allozyme alleles and the absence of at least one enzyme allele found in other populations (Bartley et al. 1985); this suggests that genetic differences between SFE White Sturgeon and its conspecifics may translate into phenotypic differences.

6. Request for Critical Habitat

Petitioners urge NMFS to designate critical habitat for the SFE White Sturgeon concurrently with listing. Critical habitat for SFE White Sturgeon should extend downstream of Central Valley “rim station” dams to the waters and fringing marshes of San Francisco Bay and its sub-embayments, and include the nearshore ocean off of San Francisco Bay (Gulf of the Farallones) and nearby coastal embayments (e.g., Bodega Bay, Tomales Bay). This would include recently documented spawning sites on the San Joaquin and Sacramento Rivers, as well as likely spawning and rearing areas on their major tributaries, including waterways used for migration to and from these spawning/rearing areas in and upstream of the Delta.

7. Recommendations for Future Management

Conserving, protecting, and restoring SFE White Sturgeon will require immediate action to simultaneously reduce key stressors, including: harmful reservoir operations and high levels of water diversion that inhibit successful spawning, rearing, and adult and juvenile migrations through the Delta; nutrient pollution that supports harmful algal blooms in San Francisco Bay-proper; and overharvest. Full restoration of this population will also require elimination and mitigation of toxic substances that SFE White Sturgeon bio-accumulate (e.g., Selenium, methyl-mercury, PCB’s, etc.). Population level impacts from ship strikes and dredging should be thoroughly investigated. And scientific research on, and long-term monitoring of, the SFE White Sturgeon population must be restored and expanded.

7.1.1. Restore Adequate Freshwater Flows to Increase Recruitment

Increased frequency of adequate river flow into, through, and out of the Delta are necessary to support successful recruitment of juveniles to the SFE White Sturgeon population. Based on the empirical relationship between Delta outflow and successful SFE White Sturgeon cohort formation, the SWRCB (2017) identified monthly average March-July Delta outflows > 37,000 cfs as necessary to protect White Sturgeon. In order to support population productivity consistent with a viable population, such flows need to occur at least once in every 4 years (~25% of years), given the reproductive interval of SFE White Sturgeon females (2-4 years). Restoring the population to its former abundance will require suitable river conditions to recur even more frequently.

Similarly, our analysis indicates that recruitment of Age 0 SFE White Sturgeon rarely occurs in years when average Sacramento River flows between April and July are < 30,000 cfs (Figure 7). New reservoir operation rules and constraints on diversions must be implemented to substantially increase the frequency and magnitude of average April-July Sacramento River flows >30,000 cfs.

Jackson et al. (2016) identified flow impairment as a likely constraint on SFE White Sturgeon reproductive success in the San Joaquin River Valley. Their study indicates that increases in streamflow during the March– May period are important drivers of spawning activity. However, they did not study the effect of flows in April-July on the successful transition of eggs into juveniles that reach the Delta. They called for increased research to refine estimates of streamflow and temperature needed to support successful spawning and larval survival in the San Joaquin and its main tributaries. Increased flows in the San Joaquin during the March-July time period will be necessary in order to study their effect on SFE White Sturgeon success. Restoration of the San Joaquin River as suitable spawning, incubation, and larval rearing habitat for SFE White Sturgeon would improve population viability through increased productivity and, eventually, abundance. Perhaps more importantly, increasing the frequency and success of spawning on the San Joaquin River and its tributaries would also be a major improvement to this fish's constrained geographic distribution, and would be a significant contribution to the population's overall viability, as a result.

In addition, flow and temperature conditions on the Feather River are unlikely to support successful SFE White Sturgeon reproduction, incubation, and dispersal in most years, due to the operations of Oroville Dam and the Thermalito infrastructure (Heublein et al. 2017). Restoration of the Feather River as suitable spawning, incubation, and early rearing habitat for SFE White Sturgeon would improve population viability through increased productivity and, eventually, abundance; it would also create additional spawning opportunities off the mainstem Sacramento River that would be a significant incremental improvement to the population's constrained geographic distribution. Research into the flow needs of White Sturgeon on this river should be investigated; needed modifications to storage and diversion operations must be implemented to support successful reproduction on the Feather River.

7.1.2. Eliminate or Substantially Reduce Migratory Barriers Through the Delta

Two main barriers severely impair migration of SFE White Sturgeon through the Delta – low dissolved oxygen and harmful algal blooms in the lower San Joaquin River around Stockton. In part, both of these migration barriers result from inadequate San Joaquin River flows. Adequate river flows are necessary to alleviate chronically low levels of dissolved oxygen (Jassby and Van Nieuwenhuyse 2005) and to prevent blooms of the toxic cyanobacteria (e.g., in the genus *Microcystis*; Berg and Sutula 2015; Lehman et al. 2013, 2020). Year round flows of ~1,000 cfs in the Stockton Deepwater Ship Channel correspond to near elimination of dissolved oxygen levels < 5mg/L (the current regulatory standard (Figure 11; Jassby and Van Nieuwenhuyse 2005) and should be mandated, at least during the December-July period, when White Sturgeon are likely to migrate through this area on their way to or from spawning habitat in the San Joaquin watershed (Figure 12).

FIGURE 11

Top panel: Box plot of summary statistics for monthly average values of daily minimum DO in the ship channel at the Rough and Ready Island continuous monitoring station (DOmin), 1983-2001 (n=19/month).

Bottom panel: Figure 6 from Van Nieuwenhuyse, E. E. 2002. Box plot of summary statistics for monthly average discharge in the San Joaquin River near Vernalis (Qvern), 1983-2001.

Source: Figures 2 and 6 from Van Nieuwenhuyse, E. E. 2002.

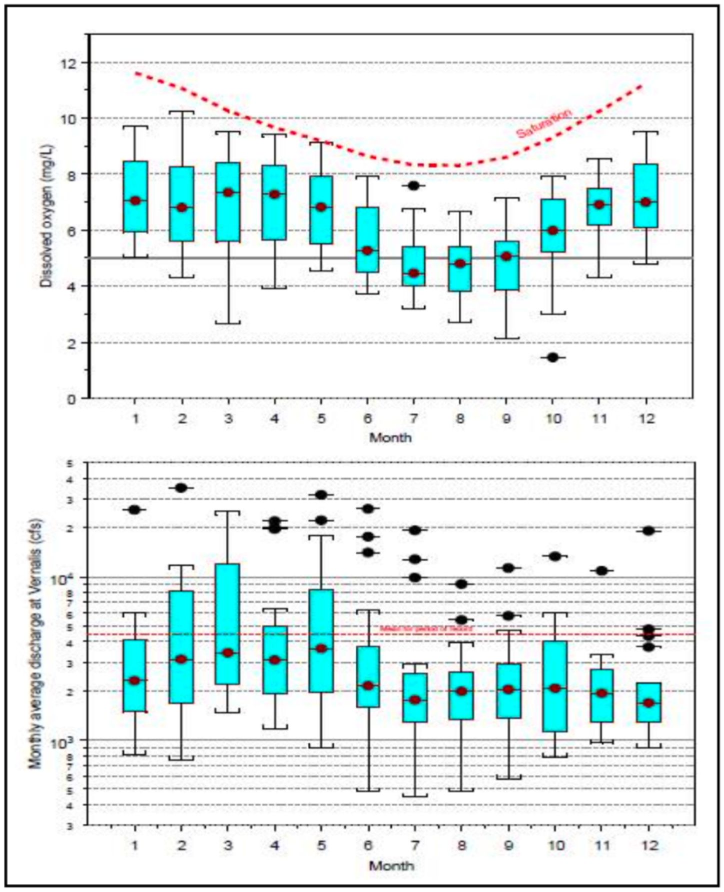


Figure 11: Distribution of flows and dissolved oxygen levels by month in the Stockton Deepwater Ship Channel. TBI 2010. Original source Figures 2 and 6 from Van Nieuwenhuyse, E. E. 2002.

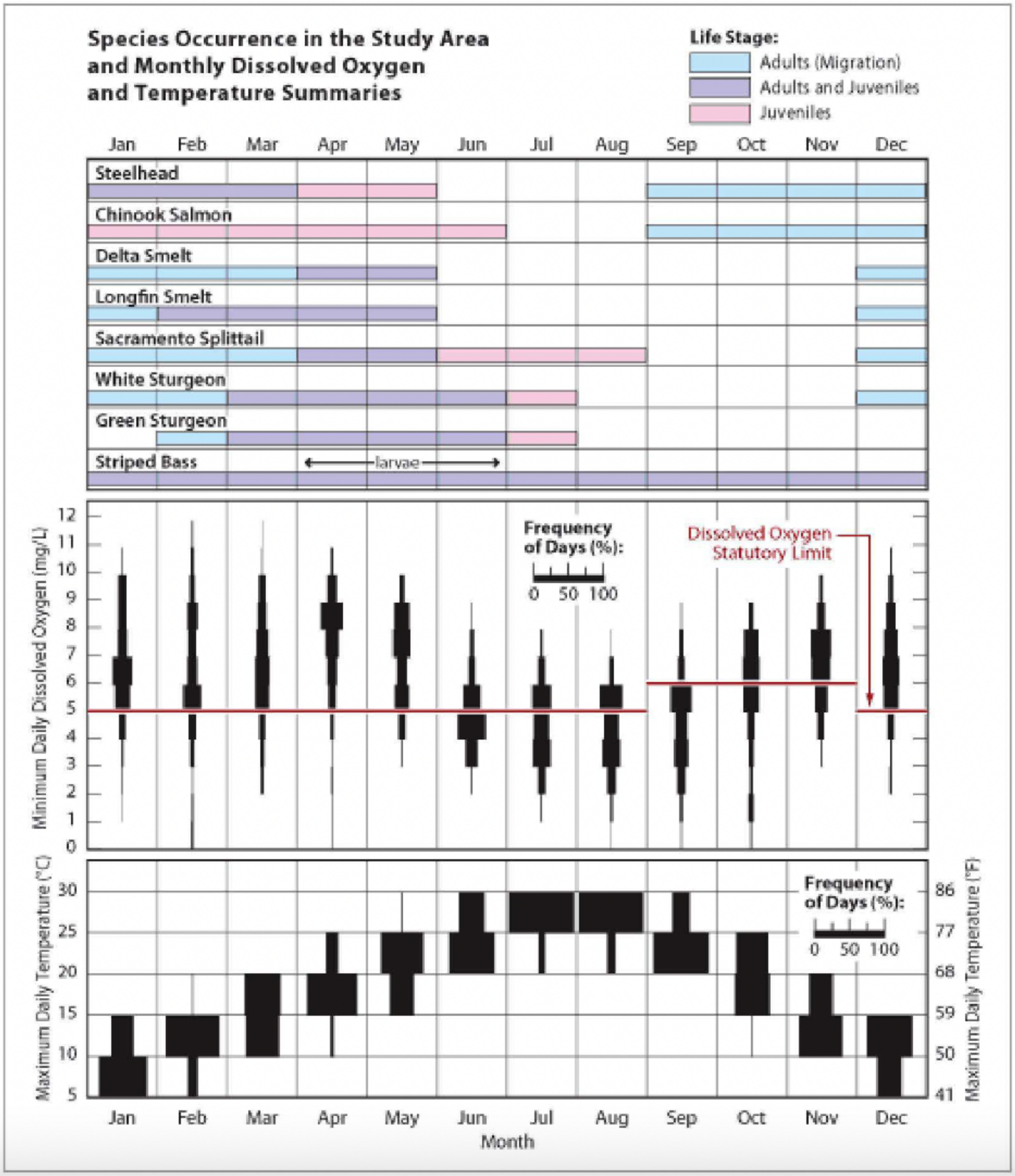


Figure 12: Timing of migration for different life stages of fish, including SFE White Sturgeon, that migrate through the Stockton Deepwater Ship Channel and the long-term distribution of temperature and dissolved oxygen levels in each month of the year. CBDA and CV RWQCB 2006.

The SWRCB adopted new standards for San Joaquin River inflow and flows on the San Joaquin's three lower tributaries in 2018 (SWRCB 2018). These updates, which have not been implemented and for which implementation is not imminent (SWRCB 2023), would require minimum flows of 1,000 cfs upstream of Stockton at Vernalis. However, about half the San Joaquin River's flow at Vernalis is distributed among other channels before it reaches Stockton, so this minimum Vernalis standard would not guarantee adequate flows to break up dissolved oxygen barriers in the lower San Joaquin River. A minimum flow standard of 1,000 cfs in the Stockton Deepwater Ship Channel (or ~ 2,000 cfs at Vernalis) should be implemented, at least during the months of December through July, when White Sturgeon migrate through this area.

At this time, it is unknown what specific flow levels are necessary to prevent toxic algal blooms in the lower San Joaquin River. Lehman (2020) found that summertime Delta outflows > ~10 Kcfs were associated with a reduction in toxic algal blooms magnitude, spatial extent, duration, and toxicity relative to drought years. In addition to the minimum flow at Vernalis (described above), the SWRCB's updates to San Joaquin River flow standards would require 40% of unimpaired flow from the Stanislaus, Tuolumne, and Merced rivers to reach the Delta between February-June. This standard has not been implemented; thus, it has had no effect on flow – and implementation of the 2018 standard is neither imminent nor certain, given the SWRCB's consideration of a "voluntary agreement" alternative. Adopted flow standards (i.e., SWRCB 2018) should be implemented while studies are conducted to determine flows necessary to prevent formation of harmful algal blooms in the lower San Joaquin watershed during the months of May-July (when blooms are likely to form and migrating sturgeon may be present).

7.1.3. Reduce Direct and Indirect Mortality Related to Water Export Operations

Episodic entrainment of juvenile sturgeon at CVP and SWP export facilities limits the SFE White Sturgeon population's ability to respond when environmental conditions would otherwise support juvenile recruitment. Most juvenile SFE White Sturgeon salvage (and by extension, most pre-screen mortality) occurs between June and November (Figure 13). It is likely that White Sturgeon mortality is higher in June than salvage data reveal, as most YOY entrained at this time are likely to be too small to screen efficiently and are vulnerable to pre-screen mortality. Current regulation of exports is least restrictive during these months. Therefore, we recommend adoption of export-related hydrodynamic criteria (e.g., limits on negative flows in the Old and Middle River distributaries of the San Joaquin River) for June-November to limit the likelihood of entrainment for SFE White Sturgeon.

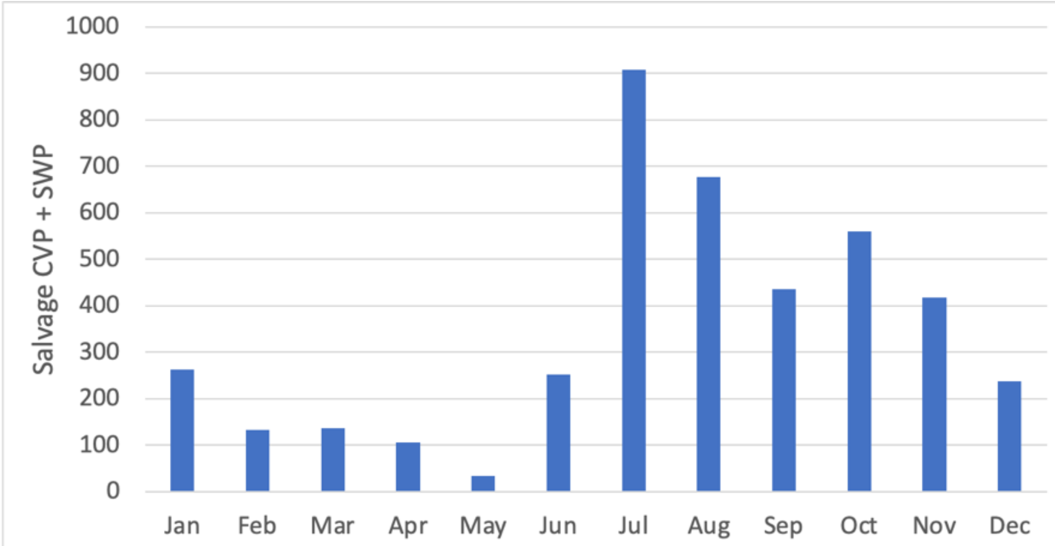


Figure 13: Combined CVP and SWP salvage of SFE White Sturgeon by month, 1993-2022.

7.1.4. Eliminate Harvest Impacts in the SFE White Sturgeon Fishery

Fishing harvest of SFE White Sturgeon has clearly been unsustainable. Until the population is determined to have recovered, fishing should be limited to catch-and-release only. A catch-and-release fishery for SFE White Sturgeon is consistent with conserving and restoring these fish as hooking mortality is extremely low. As CDFW reports:

> "Numerous studies on White Sturgeon indicate that the species is robust and tolerates the stress associated with catch and release angling well. … In a study conducted in the C.J. Strike reservoir catch and release fishery on the Snake River, ID, it was determined that adult White Sturgeon were hooked an average of 7.7 times, and landed 3.5 times, in a year (Kozfkay and Dillon 2010). This suggests that over the course of their long lives, these sturgeon experience a high level of catch and release without long term negative consequences. In studies of gear effects, it has been observed that metal tackle that has been ingested is processed and expelled quickly (Lamansky et al. 2018; Bowersox et al. 2016). Mortality as a result of angling was examined in the lower Fraser River, BC (Robichaud et al. 2006). Out of 25,219 angling events, no mortality was observed immediately upon capture and release. A subset of 96 angled fish were held in net pens for three days to evaluate delayed mortality. No mortality was observed in the first two days. Two fish died by the end of the third day (2.6% mortality); however, the authors indicated that the mortality was likely influenced by the high density of fish being held in the floating net pens (sturgeon are a benthic oriented species so captivity in a floating pen is itself a stressor) (Robichaud et al. 2006)." California Fish and Game Commission 2023 at PDF p. 56.

Although direct mortality from catch-and-release fishing appears to minimal, we recommend a prohibition on any fishing for SFE White Sturgeon over their spawning grounds between the months of December and May, inclusive. Hooking and capture generates sub-lethal stress responses (California Fish and Game Commission 2023); gravid females are likely to respond to hooking and associated handling by abandoning spawning for that year. Also, females that are already stressed by egg production and preparation for spawning may experience delayed mortality if they become further exhausted as a result of handling by anglers.

7.1.5. Reduce Nutrient Pollution in San Francisco Bay to Prevent Large Harmful Algal Blooms

Preventing future catastrophic algal blooms will require rapid and aggressive reductions in N and P loads for wastewater and oil refinery effluent disposed of in San Francisco Bay. The Regional Board anticipates drafting an update to its nutrient permit in 2024. However, adoption and implementation of the permit are uncertain, as are the permit's final terms; even under the best-case scenario, retrofitting existing infrastructure or building new infrastructure to substantially reduce nutrient loading and the risk of harmful algal blooms will require many years – perhaps a decade or more. Implementation of necessary load reductions (currently estimated to be on the order of a ~75-80% reduction in both N and P) will require significant investment by most or all of the Bay’s 37 wastewater treatment plant operators and five refineries. Funding and technical assistance to facilitate rapid transition to lower N and P loadings should be provided.

7.1.6. Improve Monitoring and Research on SFE White Sturgeon Populations

Historic and current long-term monitoring programs that generate information about SFE White Sturgeon abundance, productivity, distribution, and life-history and genetic diversity should be maintained and expanded. Monitoring SFE White Sturgeon populations is challenging because they are relatively rare, large-bodied, long-lived, and migratory. Different life stages occupy very different habitats and require different gear to sample them efficiently. As described in this petition and elsewhere (California Fish and Game Commission 2023), CDFW has numerous monitoring programs to track SFE White Sturgeon abundance. Each of these programs has generated a valuable long-term data set, however, given the life-history of this fish and the large expanse and varied habitats of the San Francisco estuary and its watershed, each time series of estimated abundance is subject to high variability. Some of this variance is intrinsic to SFE White Sturgeon population dynamics, but some of it reflects the resource-intensive nature of adequately sampling SFE White Sturgeon. Recently, the US Bureau of Reclamation cut funding for CDFW’s Adult Sturgeon Study. Dedicated funding to continue this program has not been secured. This study has provided critical, fishery-independent insight into long-term population trends for over 50 years. Funding must be replaced, and indeed, the Adult Sturgeon Study should be expanded, especially given the need to understand the population impacts of the 2022 and 2023 HAB-related fish kills. Similarly, the CDFW/Interagency Ecological Program’s Bay Study provides critical data on SFE White Sturgeon juvenile recruitment, but it is underfunded and future funding is not secure. Likewise, CDFW's White Sturgeon fishing tag program must be adequately funded to support increased participation from the fishing community. Finally, CDFW is currently unable to monitor White Sturgeon recreational fishing in the SFE beyond self-reported data. The Resources Agency should secure funds to maintain and increases each of the long-term sampling programs described above and fund additional CDFW staff to conduct frequent direct angler surveys, boat launch monitoring, and fishing regulation enforcement.

8. References

[AFS 2008]. American Fisheries Society. Jelks, H.L., S.J. Walsh, N.M. Burkhead, S. Contreras-Balderas, E. Díaz-Pardo, D. A. Hendrickson, et al. 2008. Conservation Status of Imperiled North American Freshwater and Diadromous Fishes. Fisheries 33(8): 372-407.

[AFRP 2001]. Anadromous Fish Restoration Program. 2001. Final Restoration Plan for the Anadromous Fish Restoration Program: A plan to increase natural production of anadromous fish in the Central Valley of California. Prepared for the Secretary of the Interior by the United States Fish and Wildlife Service with assistance from the Anadromous Fish Restoration Program Core Group under authority of the Central Valley Project Improvement Act. January 9, 2001.

Bartley, D.M.; Gall, G.A.E.; Bentley, B. 1985: Preliminary description of the genetic structure of white sturgeon, *Acipenser transmontanus*, in the Pacific Northwest. In: North American sturgeons: biology and aquaculture potential. F.P. Binkowski and S.I. Dorshov (Eds). W. Junk Publishers (member of Kluwer Academic Publishes Group), Dordrecht, The Netherlands, pp. 105–109. 163 pp. (ISBN90-6193-539-3).

Berg M. and Sutula M. 2015. Factors affecting the growth of cyanobacteria with special emphasis on the Sacramento-San Joaquin Delta. Southern California Coastal Water Research Project Technical Report 869 August 2015.

Blackburn, S.E., M.L. Gingras, J. DuBois, Z.J. Jackson, & M.C. Quist. 2019. Population Dynamics and evaluation of management scenarios for White Sturgeon in the Sacramento–San Joaquin River basin. North American Journal of Fisheries Management, 39(5), 896–912. https://doi.org/10.1002/nafm.10316

Castillo, G., J. Morinaka, J. Lindberg, R. Fujimura, B. Baskerville-Bridges, J. Hobbs, G. Tigan, L. Ellison. 2012. Pre-Screen Loss and Fish Facility Efficiency for Delta Smelt at the South Delta's State Water Project, California. San Francisco Estuary and Watershed Science, 10(4) Available at: http://www.escholarship.org/uc/item/28m595k4

[CBDA & CV RWQCB]. California Bay-Delta Authority and Central Valley Regional Water Quality Control Board. 2006. Dissolved Oxygen Concentrations in the Stockton Deepwater Ship Channel: Biological and Ecological Effects Model. See, in particular, pages:

http://www.sjrdotmdl.org/concept_model/bio-effects_model/lifestage.htm#wsturgeon & http://www.sjrdotmdl.org/concept_model/bio-effects_model/activity.htm

[CDFW 2010]. California Department of Fish and Game 2010. Quantifiable Biological Objectives and Flow Criteria for Aquatic and Terrestrial Species of Concern Dependent on the Delta, prepared pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009. California Department of Fish and Game, Water Branch. Sacramento, CA.

[CDFW 2015]. California Department of Fish and Wildlife. 2015. Fish Species of Special Concern in California. Sacramento: California Department of Fish and Wildlife. Prepared for CDFW by Moyle, P.B., R. M. Quiñones, J. V. Katz, and J. Weaver. www.wildlife.ca.gov

[CDFW 2020]. California Department of Fish and Wildlife. California Endangered Species Act Incidental Take Permit 2081-2019-066-00. CDFW Ecosystem Conservation Division. Sacramento, CA 94244-2090. Available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/State-Water-Project/Files/ITP-for-Long-Term-SWP-Operations.pdf

[CDFW 2023]. California Department of Fish and Wildlife. 2023. White Sturgeon Recreational Fishery: Virtual Public Meeting. Annotated slides presented by: Jonathan Nelson Dr. John Kelly, Colby Hause, Dr. Dylan Stompe. 16 May 2023. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=213229&inline

California Fish and Game Commission. 2023. Item No. 9 White Sturgeon Emergency Regulation. Staff Summary for October 11-12, 2023. Author: Jenn Bacon. Available at: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=216457&inline

[CDWR 2020]. California Department of Water Resources. 2020. Final EIR, Revisions to Part III; available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/State-Water-Project/Files/FEIR-Long-Term-Ops/Revisions-to-the-DEIR/_Part-III-Revisions-to-the-DEIR.docx

[CDWR 2022]. California Department of Water Resources. July 2022. Delta Conveyance Project Draft EIR. Available at: https://www.deltaconveyanceproject.com/planning-processes/california-environmental-quality-act/draft-eir/draft-eir-document

Cloern, J.E., T.S. Schraga, E. Nejad, C. Martin. 2020. Nutrient Status of San Francisco Bay and Its Management Implications. Estuaries and Coasts · DOI: 10.1007/s12237-020-00737-w

Demetras, N.J., B.A. Helwig, and A.S. McHuron. 2020. Reported vessel strike as a source of mortality of white sturgeon in San Francisco Bay. California Fish and Wildlife Journal, 106(1). https://doi.org/10.51492/cfwj.106.5

Diffenbaugh N.S., D.L. Swain, and D. Touma. 2015. Anthropogenic warming has increased drought risk in California. Proc Natl Acad Sci USA 112(13):3931–3936

Drauch Schreier, A.B. Mahardja, and B. May. 2013. Patterns of Population Structure Vary Across the Range of the White Sturgeon, Transactions of the American Fisheries Society, 142:5, 1273-1286, DOI: 10.1080/00028487.2013.788554. Available at: http://dx.doi.org/10.1080/00028487.2013.788554

Fish, M.A. 2010. A White Sturgeon Year-Class Index for the San Francisco Estuary and Its Relation to Delta Outflow. IEP Newsletter 23(2): 80-84. Interagency Ecological Program for the San Francisco Estuary.

Gadomski, D.M. and M.J. Parsley. 2005. Vulnerability of young white sturgeon, *Acipenser transmontanus*, to predation in the presence of alternative prey. Environmental Biology of Fishes (2005) 74:389–396. DOI 10.1007/s10641-005-3038-2

Gundersen, D.T., S.C. Zeug, R.B. Bringolf, J. Merz, Z. Jackson and M.A. Webb. 2017. Tissue contaminant burdens in San Francisco estuary white sturgeon (*Acipenser transmontanus*): implications for population recovery. Archives of Environmental Contamination and Toxicology, 73: 334-347.

Heublein, J., R. Bellmer, R. Chase, P. Doukakis, M. Gingras, D. Hampton, J. Israel, Z. Jackson, Zachary, R Johnson, O. Langness, S. Luis, E. Mora, M. Moser, L. Rohrbach, A. Seesholtz, T. Sommer, J. Stuart. 2017. Life history and current monitoring inventory of San Francisco Estuary sturgeon. National Oceanic and Atmospheric Administration, Technical Memorandum NOAA-TM-NMFS-SWFSC-589. https://doi.org/10.7289/V5/TM-SWFSC-589

Hildebrand, L.R., A. Drauch Schreier, K. Lepla, S.O. McAdam, J. McLellan, M. J. Parsley, V. L. Paragamian, S. P. Young. 2016. Status of White Sturgeon (*Acipenser transmontanus* Richardson, 1863) throughout the species range, threats to survival, and prognosis for the future. J. Appl. Ichthyol. 32, 261–312.

Hutton P.H., J.S. Rath, S.B. Roy. 2017. Freshwater flow to the San Francisco Bay–Delta estuary over nine decades (Part 1): Trend evaluation. Hydrol Process 31:2500– 2515. *https://doi.org/10.1002/hyp.11201*

Israel, J., A. Drauch, and M. Gingras. 2009. Life History Conceptual Model White Sturgeon (*Acipenser transmontanus*). Developed for the Sacramento-San Joaquin Delta Regional Ecosystem Restoration Implementation Plan Available at: http://www.essexpartnership.com/wp-content/uploads/2010/10/WhiteSturgeon-_1_.pdf

Jackson, Z.J., Gruber, J.J., & Van Eenennaam, J.P. (2015). White sturgeon spawning in the San Joaquin River, California, and effects of water management. *Journal of Fish and Wildlife Management*, *7*(1), 171–180. https://doi.org/10.3996/092015-jfwm-092

Jassby, A.D. and E.E. Van Nieuwenhuyse. 2005. Low dissolved oxygen in an estuarine channel (San Joaquin River, California): Mechanisms and models based on long-term time series. San Francisco Estuary and Watershed Science 2:1–33.

Klimley, A.P., J.J. Cech, D.E. Cocherell, N.A Fangue, M. Gingras, Z. Jackson, E.A. Miller, E.A. Mora., J.B. Poletto, A.M. Schreier, A. Seesholtz, K.J. Sulak, M.J. Thomas, D. Woodbury, M.T. Wyman. 2015. Sturgeon in the Sacramento–San Joaquin Watershed: New Insights to Support Conservation and Management. San Francisco Estuary and Watershed Sciences 13(4). Available at: http://escholarship.org/uc/item/7892b2wp

Krieger, J., A.K. Hett, P.A. Fuerst, E. Artyukhin, and A. Ludwig. 2008. The molecular phylogeny of the order Acipenseriformes revisited. J. Appl. Ichthyol. 24 (Suppl. 1) (2008), 36–45. doi: 10.1111/j.1439-0426.2008.01088.x

Kudela, R.M., M.D.A., Howard. S. Monismith, H.W. Paerl 2023. Status, Trends, and Drivers of Harmful Algal Blooms Along the Freshwater-to-Marine Gradient in the San Francisco Bay–Delta System. San Francisco Estuary and Watershed Science, 20(4). Available at: https://escholarship.org/uc/item/1dz769db DOI: 10.15447/sfews.2023v20iss4art6

Kynard, B. and E. Parker. 2005. Ontogenetic behavior and dispersal of Sacramento River white sturgeon, *Acipenser transmontanus*, with a note on body color. Environmental Biology of Fishes (2005) 74: 19–30. DOI 10.1007/s10641-005-2198-4

Lehman, P.W.K. Marr, G.L. Boyer, S. Acuna, and S.J. Teh. 2013. Long-term trends and causal factors associated with *Microcystis* abundance and toxicity in San Francisco Estuary and implications for climate change impacts. Hydrobiologia 718:141–158 DOI 10.1007/s10750-013-1612-8

Lehman, P.W., T. Kurobe, S.J. Teh. 2020. Impact of extreme wet and dry years on the persistence of *Microcystis* harmful algal blooms in San Francisco Estuary. Quaternary International, https://doi.org/10.1016/j.quaint.2019.12.003

Leidy, R. A. 2007. Ecology, assemblage structure, distribution, and status of fishes in streams tributary to the San Francisco Estuary, California. Ecology, Assemblage Structure, Distribution, and Status of Fishes in Streams Tributary to the San Francisco Estuary, California | San Francisco Estuary Institute. Retrieved February 7, 2023, from https://www.sfei.org/leidy_No530/index.html

Lindley, S.T. R. S. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene, C. Hanson, B.P. May, D. R. McEwan, R.B. MacFarlane, C. Swanson, J.G. Williams. 2007. Framework for Assessing Viability of Threatened and Endangered Chinook Salmon and Steelhead in The Sacramento-San Joaquin Basin. Vol. 5, Issue 1. Article 4. http://repositories.cdlib.org/jmie/sfews/vol5/iss1/art4

McElhany P., M. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. of Commerce. NOAA Tech. Memo. NMFS- NWFSC-42,156 pp.

Miller, E.A., G.P. Singer, M.L. Peterson, E.D. Chapman, M.E. Johnston, M.J. Thomas, R.D. Battleson, M. Gingras, & A.P. Klimley. (2020). Spatio-temporal distribution of green sturgeon (*Acipenser medirostris*) and white sturgeon (*A. transmontanus*) in the San Francisco Estuary and Sacramento River, California. *Environmental Biology of Fishes*, *103*(5), 577–603. https://doi.org/10.1007/s10641-020-00972-x

Moyle, P.B. 2002. Sturgeons, Acipenseridae. In *Inland Fishes of California* (pp. 106–113). essay, University of California Press.

Moyle, P.B. and A. Rypel. 2023. Monster Fish: Lessons for Sturgeon Management in California. California WaterBlog. Posted on May 14, 2023 by Andrew Rypel. Available at: https://californiawaterblog.com/2023/05/14/monster-fish-lessons-for-sturgeon-management-in-california/

Paragamian, 2012. Kootenai River white sturgeon: synthesis of two decades of research. Endangered Species Research, 17: 157–167. doi: 10.3354/esr00407 Available at: https://www.int-res.com/articles/esr_oa/n017p157.pdf

Parsley, M.J. and L.G. Beckman. 1994. White sturgeon spawning and rearing habitat in the lower Columbia River. North American Journal of Fisheries Management 14: 812–827.

[Reclamation]. U.S. Bureau of Reclamation. 2019 Final Biological Assessment regarding Reinitiation of Consultation on the coordinated long-Term Operations of the Central Valley Project and State Water Project, Chapter 5: Effects Analysis. October 2019. Available at: https://www.usbr.gov/mp/bdo/lto/biop.html

Reis, G.J., J.K. Howard, and J.A. Rosenfield. 2019. Clarifying Effects of Environmental Protections on Freshwater Flows to—and Water Exports from—the San Francisco Bay Estuary. San Francisco Estuary and Watershed Science, 17(1). Available at: https://escholarship.org/uc/item/8mh3r97j

Rosenfield, J.A., 2002. Pattern and process in the geographical ranges of freshwater fishes Global Ecology & Biogeography.11:323–332

[SFEI 2016]. San Francisco Estuary Institute. San Francisco Estuary Institute. 2016. San Francisco Bay Nutrient Management Strategy Science Plan. Available at: https://sfbaynutrients.sfei.org/sites/default/files/2016_NMSSciencePlan_Report_Sep2016.pdf

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bulletin 184, Fisheries Research Board of Canada. Ottawa.

Sellheim, K., M. Willmes, L. Lewis, J. Sweeney, J. Merz, and J. Hobbs. 2022. Diversity in habitat use by White Sturgeon revealed using fin ray geochemistry. Frontiers in Marine Science 9: 859038. doi: 10.3389/fmars.2022.859038

Schreier, A., P.B. Moyle, N.J. Demetras, S. Baird, D. Cocherell, N.A. Fangue, K. Sellheim, J. Walter, M. Johnston, S. Colborne, L.S. Lewis, and A.L. Rypel. 2022. White sturgeon: is an ancient survivor facing extinction in California? California WaterBlog. Posted on November 6, 2022 by Andrew Rypel. Available at: https://californiawaterblog.com/2022/11/06/white-sturgeon-is-an-ancient-survivor-facing-extinction-in-california/

[Sites RDEIR/SDEIS 2021]. Sites Reservoir Project Revised Draft Environmental Impact Report/Supplemental Draft Environmental Impact Statement. November 2021. State Clearinghouse #2001002009. Prepared by: Sites Project Authority & Bureau of Reclamation, Appendix 5c, available at: https://sitesproject.org/wp-content/uploads/2021/11/RDEIR-SDEIS-App05C-Upper-Sac-River-Daily-River-Flow-Ops-Model.pdf

Skinner, J.E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay Area. Water Projects Branch, Report #1. California Department of Fish and Game. Resources Agency of California. Available at: https://babel.hathitrust.org/cgi/pt?id=mdp.39015006169141&seq=3

Smith, W.E., L. Polansky, and M.L. Nobriga. 2021. Disentangling risks to an endangered fish: using a state-space life cycle model to separate natural mortality from anthropogenic losses. Can. J. Fish. Aquat. Sci. 00: 1–22 (0000) dx.doi.org/10.1139/cjfas-2020-0251

Stanford, B., K. Ridolfi, and B. Greenfield. San Francisco Estuary Institute. 2009. Summary Report: Green Sturgeon, Longfin Smelt, and Dredging Operations in the San Francisco Estuary. Available at: https://www.sfei.org/sites/default/files/biblio_files/Green_sturgeon_and_Longfin_smelt_symposia_summary_report_04-07-10.pdf

[SWRCB 2010]. State Water Resources Control Board. 2010. Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem Prepared Pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009. California Environmental Protection Agency. Sacramento, CA. Available here: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/final_rpt080310.pdf

[SWRCB 2016]. State Water Resources Control Board. 2016. Technical Report on the Scientific Basis for Alternative San Joaquin River Flow and Southern Delta Salinity Objectives. Appendix C to the "Final Substitute Environmental Document in Support of Potential Changes to the Water Quality Control Plan for the San Francisco Bay-Sacramento San Joaquin Delta Estuary San Joaquin River Flows and Southern Delta Water Quality. State Water Resources Control Board, California Environmental Protection Agency. Sacramento. Available at: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/2018_sed/docs/appx_c.pdf

[SWRCB 2017]. State Water Resources Control Board. 2017. Scientific Basis Report in Support of New and Modified Requirements for Inflows from the Sacramento River and its Tributaries and Eastside Tributaries to the Delta, Delta Outflows, Cold Water Habitat, and Interior Delta Flows. California Environmental Protection Agency, Sacramento, CA. Available at: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/california_waterfix/exhibits/docs/PCFFA&IGFR/part2/pcffa_168.pdf

[SWRCB 2018]. State Water Resources Control Board. 2018. Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary December 12, 2018. State Water Resources Control Board, California Environmental Protection Agency. Sacramento. Available at: https://www.waterboards.ca.gov/plans_policies/docs/2018wqcp.pdf

[SWRCB 2023]. State Water Resources Control Board. 2023. Executive Summary *in* Draft Staff Report/Substitute Environmental Document in Support of Potential Updates to the Water Quality Control Plan for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary for the Sacramento River and its Tributaries, Delta Eastside Tributaries, and Delta. State Clearinghouse #2012012053. Available at: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/2023/staff-report/ch01-execsumm.pdf

Stewart, A.R., F. Feyrer, R.C. Johnson. 2020. Resolving selenium exposure risk: Spatial, temporal, and tissue-specific variability of an endemic fish in a large, dynamic estuary, Science of The Total Environment, Volume 707. https://doi.org/10.1016/j.scitotenv.2019.135919.

Stompe, D.K. and J.A. Hobbs. 2023. California Department of Fish and Wildlife Adult Sturgeon Study, Sacramento-San Joaquin Watershed, 1954-2022 ver 1. Environmental Data Initiative. https://doi.org/10.6073/pasta/521d2adb9362113812a04f2bc4623a31 (Accessed 2023-11-09).

[TBI 2010]. The Bay Institute. 2010. Gone with the Flow: How the alteration of freshwater flows is killing the Bay-Delta ecosystem. Available at: https://bayecotarium.org/wp-content/uploads/gone-with-the-flow-.pdf

[TBI 2012]. The Bay Institute. 2012. Collateral Damage: A citizen's guide to fish kills and habitat degradation at the state and federal water project pumps in the Delta. Available at: https://bayecotarium.org/wp-content/uploads/collateraldamage.pdf

[TBI 2016]. The Bay Institute. 2016. San Francisco Bay: the freshwater starved estuary. Bay.org. Available at: https://h8b186.p3cdn2.secureserver.net/wp-content/uploads/2016/09/Freshwater_Report.pdf

Ulaski, M.E., S.E. Blackburn, Z.J. Jackson, & M.C. Quist. 2022. Management goals for conserving white sturgeon in the Sacramento–San Joaquin River basin. *Journal of Fish and Wildlife Management*, *13*(2), 334–343. https://doi.org/10.3996/jfwm-21-070

[USFWS 2022]. U.S. Fish and Wildlife Service. 2022. Species Status Assessment for the San Francisco Bay-Delta Distinct Population Segment of the Longfin Smelt. U.S. Fish and Wildlife Service. San Francisco Bay-Delta Fish and Wildlife Office, Sacramento, California. Including Appendices A–G. Available at: https://www.fws.gov/sites/default/files/documents/08_12_22_LFS_Final_SSA_508_compliant.pdf

Van Nieuwenhuyse, E.E. 2002. Statistical Model of Dissolved Oxygen Concentration in the San Joaquin River Stockton Deepwater Channel at Rough and Ready Island, 1983- 20011, Draft Technical Memorandum. Submitted to the San Joaquin Dissolved Oxygen TMDL Technical Advisory Committee. March 28, 2002, revised April 18, 2002.

Welch, D.W., S. Turo, and S.D. Batten. 2006. Large-scale marine and freshwater movements of White Sturgeon. Transactions of the American Fisheries Society 135:386–389.

Willis, S.C.; B. Parker, A.D. Schreier.; R. Beamesderfer, D. Miller, S. Young, and S.R. Narum. 2022. Population Structure of White Sturgeon (*Acipenser transmontanus*) in the Columbia River Inferred from Single-Nucleotide Polymorphisms. Diversity 2022,14,1045. https:// doi.org/10.3390/d14121045

Zeug S.C., A. Brodsky, N. Kogut, A.R. Stewart, J.E. Merz. 2014. Ancient fish and recent invaders: white sturgeon *Acipenser transmontanus* diet response to invasive-species-mediated changes in a benthic prey assemblage. Mar Ecol Prog Ser 514:163-174. https://doi.org/10.3354/meps11002