Sturgeon Scientific Literature and Annotations

By Tom Cannon, thomascannon0@gmail.com

A. **2011 San Joaquin River Sturgeon Spawning Survey (Gruber et al. 2012)**

- *White sturgeon (Acipenser transmontanus) in the Sacramento-San Joaquin river system were previously known to spawn only in the Sacramento River within a 86 km reach between Knight's Landing (RK 145) and Colusa (RK 231).*

Comment: White sturgeon were noted historically in the Sacramento and San Joaquin Rivers and their tributaries.

- *The results of this survey confirm that white sturgeon do spawn in the San Joaquin River and may be an important source of production for the white sturgeon population in the Sacramento-San Joaquin river system.*
- *In April 2011, the collection of white sturgeon eggs documented white sturgeon spawning in the San Joaquin River.*
- *Average daily discharge in the San Joaquin River in early 2011 was two to three times higher than the mean daily discharge for water years 1991 to 2010 (Figure 5). As speculated by researchers, river discharge levels of this magnitude triggered white sturgeon to enter and spawn within the San Joaquin River System.*

Comment: Juvenile white sturgeon were collected in the daily salvage at the Tracy Pumping Plant in summer of wet year 2023 under high exports (Figure A-1). River flows had been very high in May and June in the San Joaquin River (Figure A-2) upstream of the Delta. That fact along with salvage predominantly occurring only at the Tracy facility indicates that these salvaged juvenile white sturgeon were likely from the San Joaquin River. Such high flows in wet years are likely conducive to white sturgeon attraction and spawning in the San Joaquin River system. Spawning usually occurs when water temperatures are 55-65ºF (13-18ºC), which were the conditions in the lower San Joaquin River above the Delta in spring 2023. The presence of juvenile sturgeon in the summer salvage indicates this period marked key river emigration to Bay-Delta nursery habitats from the San Joaquin River. However, Lower San Joaquin River and Old River water temperatures (Figures A-2 to A-4) in summer 2023 ranged from 70-80ºF, well above the 68ºF safe level for juvenile sturgeon, and often well above the high-stress level of 73ºF. Even if closure of the Head of Old River on the San Joaquin River were considered, water temperatures are generally excessive (>75ºF) by July for juvenile sturgeon survival through the East, South, and Central Delta – even in wet years. Though sturgeon may spawn in the Lower San Joaquin River, their potential contribution to recruitment in the adult Bay-Delta population is therefore likely minimal in all water year types. It is for this reason that any juvenile sturgeon salvaged in summer (or captured in monitoring in the lower San Joaquin River or the Delta) should be transported to our proposed sturgeon conservation hatchery for rearing and release to the Bay. It may be best in summer to leave the HORB open to allow salvage or the rescue option, otherwise the juvenile sturgeon may be lost in the interior Delta. Juvenile sturgeon can be captured at the HORB in summer and reared in the conservation hatchery. In drier years, we expect less spawning in the lower San Joaquin River and few juvenile sturgeon to survive to reach the HORB unless determined otherwise by monitoring.

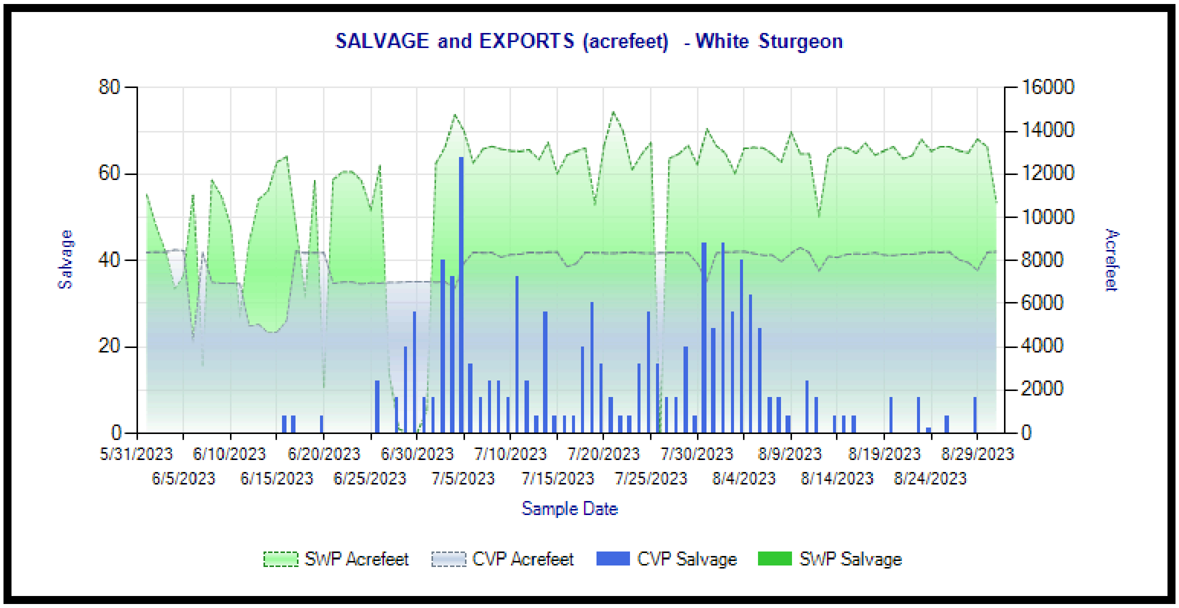

Figure A-1. Salvaged juvenile white sturgeon at South Delta pumping plant fish facilities in 2023.

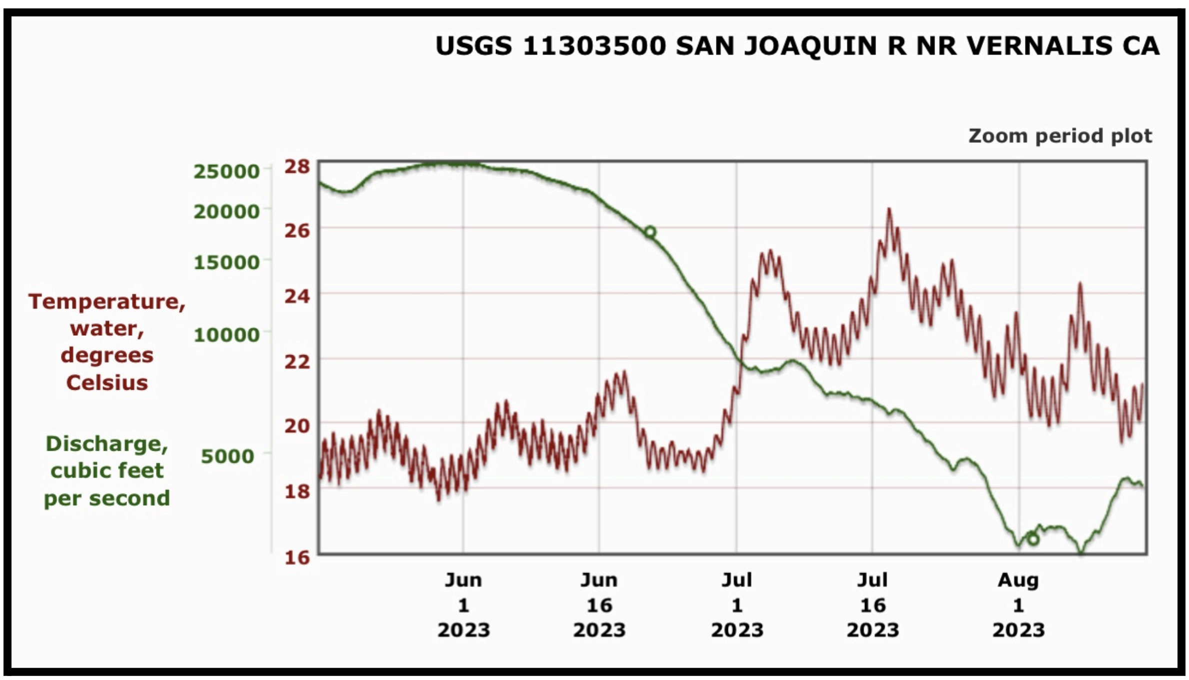

Figure A-2. May-August 2023 streamflows and water temperatures in the lower San Joaquin River upstream of the Delta at Vernalis.

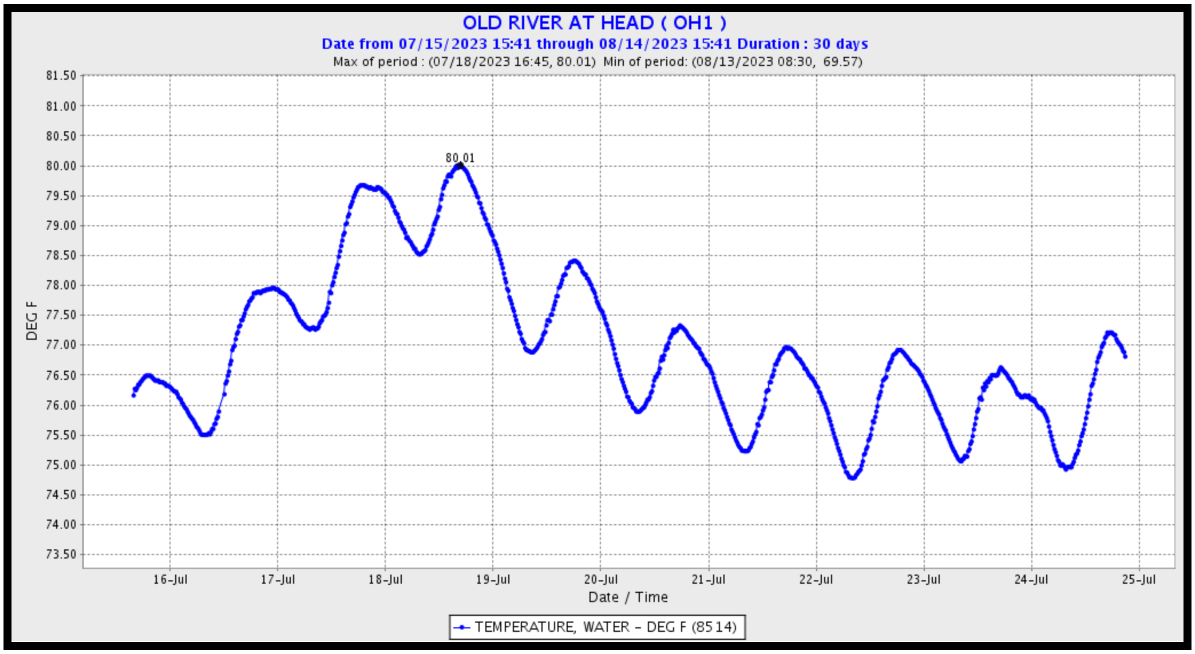

Figure A-3. Water temperature at the Head of Old River on the San Joaquin River in July 2023.

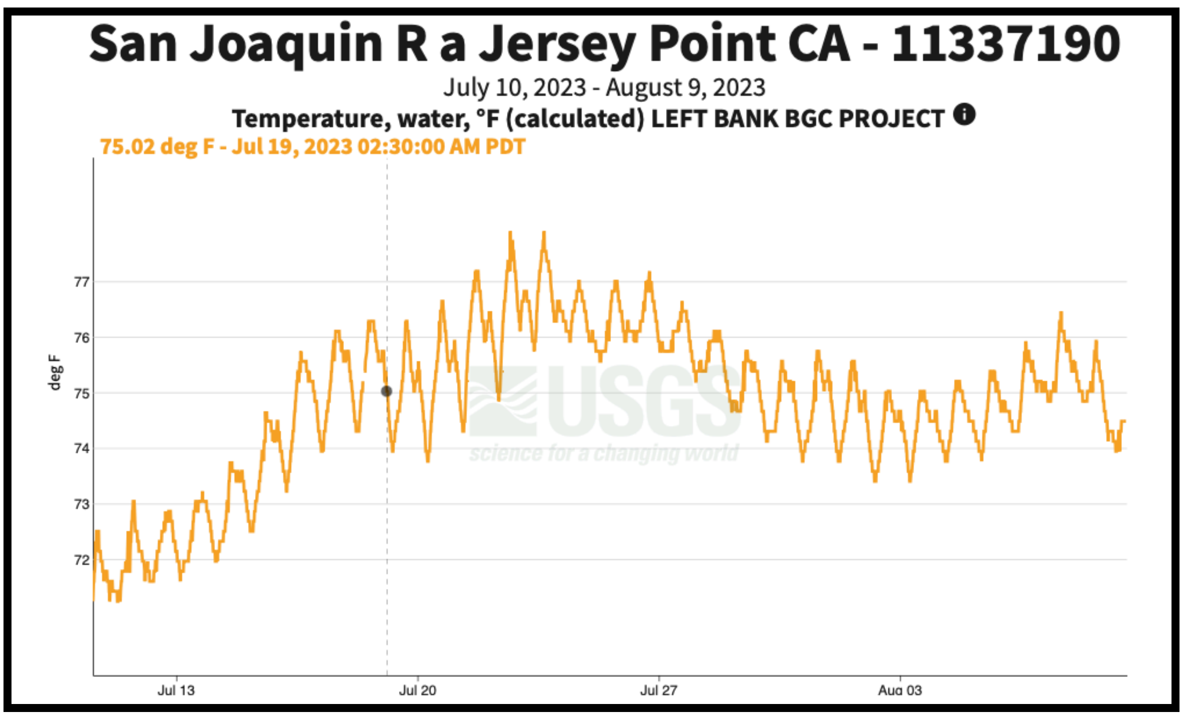

Figure A-4. Water temperature at Jersey Point in the West Delta in the lowermost San Joaquin River channel in summer 2023.

B. Genetic techniques inform conservation aquaculture of the endangered Kootenai River white sturgeon Acipenser transmontanus (Schreier et. al., 2012)

- *Conservation aquaculture is a tool that, used in concert with ecological restoration and harvest regulation, can protect the unique genetic, morphological, and behavioral characteristics of imperiled populations. Although conservation aquaculture programs are designed to minimize genetic impacts on wild populations, founder effects, domestication, and inbreeding may occur. Genetic monitoring may be used in the context of adaptive management to reduce deleterious genetic impacts of captive breeding in wild populations. Here we use the conservation aquaculture program for the endangered Kootenai River white sturgeon Acipenser transmontanus as a case study to illustrate how genetic tools might improve captive breeding programs for large river fishes. We used microsatellite markers to reveal very low levels of genetic diversity in the Kootenai River white sturgeon relative to other populations across the species' range. We show that by using high numbers of broodstock, the conservation aquaculture program has captured 96% of the population's microsatellite diversity in hatchery-released progeny in only 10 yr. We validate the power of parentage analysis to identify family relationships between individual white sturgeon using a panel of 18 microsatellite loci. Parentage analysis will become crucial for inbreeding avoidance in the Kootenai River white sturgeon aquaculture program in ~2020 to 2030, when the majority of broodstock available for captive breeding will originate from the hatchery.* (p65)

  Comment: Studies like this confirm a conservation hatchery for white sturgeon with the goal of maintaining or improving genetic diversity is feasible.

- *River fishes worldwide are threatened by habitat fragmentation and loss, modification of natural flow regimes, pollution, loss of habitat connectivity due to impoundment, invasive species, and overharvest (Jelks et al. 2008). Although restoration of habitat and reduction or elimination of harvest are the best means to recover vulnerable fish populations, lack of available personnel, political will, and/or funding make these actions time consuming and difficult to implement. In addition, the current imperiled status of many fish populations often is the result of many interrelated environmental and demographic changes that have occurred over time. It may be difficult to pinpoint the most limiting factor(s) on which to focus management action for population restoration. One conservation tool that might be used in concert with the identification of limiting factors and ecological restoration is conservation aquaculture.* (p65)

  Comment: We also recommend a conservation hatchery to rescue and rehabilitate wild (natural-born) sturgeon to increase the population's size and diversity and help pinpoint limiting factors in population abundance. Hatchery rescued/reared fish can be used to help understand sturgeon survival factors through marking, radio tagging, and pit tagging, as is now done with hatchery salmon smolts.

- *Conservation aquaculture is the use of captive propagation to sustain imperiled species or populations and preserve local characteristics in the face of severe declines. Although similar to supplementation programs in that hatchery releases occur into pre-existing natural populations, the goals of conservation and traditional supplementation hatch- eries are quite different. Traditional supplementation hatcheries primarily seek to increase the abundance of target populations, often to enhance fisheries or attain related fisheries management goals, while in conservation aquaculture programs, the preservation of unique genetic diversity, phenotypes, and behaviors is of ultimate concern (Anders 1998, H. Kincaid unpubl.). Conservation aquaculture* *programs might be seen as a 'stopgap' measure to slow population decline while restoration activities to alleviate conditions limiting natural recovery are underway (Ireland et al. 2002a,b). Traditional supplementation hatcheries, however, are often viewed as mitigation for the effects of environmental decline in and of themselves. Special techniques to minimize genetic changes in the hatchery environment are particularly emphasized in conservation aquaculture programs to minimize changes to the natural population as well as to maximize survival of captive-bred progeny.* (p66)

- *Although it is inevitable that captive breeding will induce some genetic changes in natural populations (Waples 1999), genetic tools can be used in the adaptive management of conservation aquaculture programs to minimize these changes. Genetic monitoring allows managers to characterize baseline levels of genetic diversity in a target population which can be used to evaluate genetic diversity loss as a result of the conservation aquaculture program. Broodstock numbers, mating schemes, and release strategies can then be adaptively modified to minimize genetic diversity loss. Multilocus genotypes can be used as 'genetic tags' to track broodstock used in the hatchery and re-released into the wild. Relatedness analyses (Kozfkay et al. 2008) or parentage assignment (this study) can be used to prevent mating close relatives when pedigree information is limited, thus reducing the likelihood of inbreeding depression.* (p66)
- *From a genetic perspective, large fishes are particularly suited for conservation aquaculture due to their long generation time and iteroparity. Species with lengthy generation times can retain genetic diversity for long periods, even in the face of severe demographic declines.* (p66)
- *Multi-year stocking programs using unique wild-captured broodstock each year have been shown to reduce founder effects traditionally associated with hatchery programs (Heggenes et al. 2006, Drauch & Rhodes 2007, Rourke et al. 2009, 2010).* (p66)

C. IMPROVED FISHERIES MANAGEMENT THROUGH LIFE STAGE MONITORING: THE CASE FOR THE SOUTHERN DISTINCT POPULATION SEGMENT OF NORTH AMERICAN GREEN STURGEON AND THE SACRAMENTO-SAN JOAQUIN RIVER WHITE STURGEON. Heublein et. al. 2017. NOAA Technical Memorandum NMFS. SEPTEMBER 2017

Preface:

- *"Potential increases in consecutive recruitment failures in SFE sturgeon raise concern about the resilience of sDPS green sturgeon and the sustainability of a harvestable white sturgeon stock. Fundamental sturgeon demographic measures are lacking in the existing monitoring and analytical framework. As a result, managers are unable to determine specific causes of poor recruitment, accurately track green sturgeon listing status under the Federal Endangered Species Act, or measure sturgeon population responses to management of water resources and/or harvest regulations."* (piii)

Comment: We agree with the conclusions in this paper and have included the recommendations in our recommendations.

Executive Summary:

- As *a consequence of this monitoring inadequacy, validation of indicators of strong green sturgeon production is limited by a reliance on signals of cohort success observed in adult* *surveys only. In other words, testing of management actions intended to increase sturgeon spawning success (e.g., adult passage at dams) or understanding population-level effects of presumably poor spawning conditions (e.g., the recent drought) requires a 15-year-plus time interval for cohorts to reach the adult stage. For white sturgeon, measures of recruitment generated from data collected in juvenile and adult surveys have provided managers with a coarse flow-recruitment mechanism for year-class strength (CDFG 1992; Fish 2010). However, the specific life stage where flows influence white sturgeon recruitment remains uncertain. In turn, managers are unable to accurately predict the response of either sturgeon species to actions such as pulse flows, spawning habitat restoration, or harvest regulations.*

Comment: We agree. Many long-term monitoring programs target pelagic or shore-oriented species and do not cover sturgeon. The Red Bluff screw trap surveys measure the production of green sturgeon above Red Bluff to some degree, but do not address white sturgeon; they rarely spawn as far upstream as Red Bluff. Our recommendations focus on spawning and early rearing conditions in the Lower Sacramento River, the Lower San Joaquin River, and the Delta, as well as subadult and adult habitat conditions in the Bay. We recommend minimal harvest of white sturgeon until the population status is well understood and supplementation recruitment enhances the harvestable stock. Measures taken that directly or indirectly support sturgeon should be monitored to address their effectiveness.

- *Here we used monitoring inventories and life history descriptions of southern Distinct Population Segment (sDPS) green sturgeon and SFE (Sacramento-San Joaquin River) white sturgeon from Heublein et al. (2017) to develop conceptual models by species life stage. The conceptual models include 41 combined hypotheses involving factors affecting sturgeon life stage transitions (Table 1; Figures 2 through 8).*
- *We then developed 17 monitoring recommendations to potentially test these hypotheses and prioritized 15 recommendations addressing core areas of sturgeon demography and management (Table 1).*
- *In SFE watershed monitoring, the annual collection of young sturgeon is typically low, and any potential new surveys consistently capturing early life stages will likely require a multi-year development period. Based on this, management of these species requires the continuation or expansion of surveys currently encountering early life stages of sturgeon (Heublein et al. 2017) and additional development of baseline surveys throughout the range of both species.*

Comment: We agree and prescribe the specific monitoring of spawning areas and juvenile migration routes.

- *Long-term spawning surveys should be implemented in primary sturgeon spawning areas (Sacramento and San Joaquin rivers), while spawning surveys should be implemented as needed in areas where spawning appears to be episodic (Feather, Bear, and Yuba rivers). Habitat in egg collection locations should be mapped or surveyed to develop suitable spawning habitat criteria and quantify available habitat. Long-term larval surveys should also be implemented in spawning or larval dispersal areas where surveys are currently lacking (e.g., the middle Sacramento River).*

Comment: We agree; included in our recommendations.

- *The white sturgeon juvenile year-class index (YCI) provides managers with an early forecast of future adult abundance as well as a linkage between cohort success and spawning and* *rearing conditions (CDFG 1992; Fish 2010). In turn, recruitment information is critical for multiple aspects of sturgeon management ranging from harvest limits to spawning and rearing habitat suitability guidelines. Hence, a green sturgeon YCI should be developed along with improvements to white sturgeon YCI precision, and this could most likely be accomplished through an increase in sampling effort in existing SFE trawl surveys. Because juvenile green sturgeon are less abundant in the SFE than juvenile white sturgeon, long-term sampling of green sturgeon juveniles (i.e., benthic trawl) should also occur in upper and middle Sacramento River habitats where they appear to be more common.*

Comment: While the Bay otter trawl survey (see Figure 4) provides some information on the seasonal occurrence, distribution and annual variation of young white sturgeon in the Bay, it is unreliable for age-0 recruitment estimates. We recommend the release of tagged (PBT or physical tag) age-1 white sturgeon into the Bay from a conservation hatchery and a comprehensive mark-recapture Peterson estimate of annual recruitment and age-structure model of the population.

- *Detection of green sturgeon implanted with acoustic tags have revolutionized our ability to generate abundance estimates and provide vital information on migration distances and spawn timing and locations (Moser et al. 2016, Klimley et al. 2015). The current run-size estimate model for green sturgeon in the Sacramento River requires acoustic detection of tagged green sturgeon by the Vemco VR2 array in spawning habitat (Mora 2016). A similar run-size survey for white sturgeon would also require acoustic detection of tagged adult white sturgeon in spawning habitat.* (p2)

  Comment: This program element works well for green sturgeon because they are captured in relatively large numbers at Red Bluff. If age-0 white sturgeon can be captured at Valley flood control weirs, the DCC, the HORB, and salvage collections, then a similar population abundance model may be possible. A comprehensive PBT database and analyses may also provide population statistics that can serve for run-size estimates and population recruitment estimates.

- *Demographic criteria for effective population size are a cornerstone for evaluating Federal Endangered Species Act (ESA) listing status of anadromous fish of the SFE watershed (NMFS 2014). Any new genetic population models and abundance estimates should be used to determine effective population size and verify existing run-size estimates or fishery-dependent abundance measures in both species. Population genetics (i.e., genotyping and parentage) should be refined (along with non-lethal genetic techniques for early life stages) and applied to archived tissues and any new tissues. New life history and genetic information should also be used to understand the contribution of alternative spawning areas or life history strategies to the population and elucidate potential subpopulation structure. Much like the tag detection database described above, research should be streamlined by supporting a publicly accessible sturgeon genome and microchemistry database.*

  Comment: We agree and support the recommended sturgeon genetic program and monitoring and assessment actions provided in this paper (see Table 1 in paper).

D. Population Dynamics and Evaluation of Management Scenarios for White Sturgeon in the Sacramento–San Joaquin River Basin. Blackburn et al 2019

- *All sturgeons share life history characteristics (e.g., long life span, periodic spawning, and delayed maturation) that make them exceptionally vulnerable to anthropogenic disturbances. Most sturgeon species are imperiled due to habitat degradation, altered flow and temperature regimes, and overharvest. (p896)*

  Comment: While generally true, long life span, high fecundity, and multiple spawnings provide for strong resilience and persistence – assuming these traits are sustained. These traits also offer a strong affinity for population recovery. Any fish population can succumb to anthropogenic disturbances and high harvest rates. It so happens that all these stresses affect the sturgeon of the Central Valley to a great degree. We recommend actions to alleviate these stresses in each category.

- *Although White Sturgeon are relatively abundant and widespread, commercial and recreational fisheries and alterations to large river habitats (e.g., hydroelectric dam construction) have reduced their abundance and distribution.*
- *the SSJ population of White Sturgeon does not warrant federal protection at this time (Paragamian et al. 2005; Hildebrand et al. 2016). However, results from recent monitoring studies by the California Department of Fish and Wildlife (CDFW) have provided evidence that the population is declining; it is considered a species of high concern by the state of California (Moyle et al. 2015; Hildebrand et al. 2016). As such, preventing further declines of White Sturgeon in the SSJ has become a recent focus of the CDFW and the U.S. Fish and Wild- life Service (USFWS).* (p897)
- *For White Sturgeon, the CVPIA has an objective of a sustained increase in the number of age-15 White Sturgeon to 11,000 individuals based upon CDFW population estimates from 1956 to 1991; this objective has yet to be achieved (Gingras and DuBois 2013).* (p897)

  Comment: This suggested CVPIA goal is for recruitment of age-15 adult sturgeon into the adult population. It is a reasonable place to start, but should extend to adult recruitment analyses derived from comprehensive adult population monitoring and abundance estimates. Figure 1 suggests a reasonable initial goal of 100,000 harvestable adults under a 5% harvest.

- *White Sturgeon were historically abundant in the SSJ, but altered habitat and hydrological conditions coupled with overexploitation are considered to have caused the declines in SSJ population abundance and distribution…. Unregulated commercial harvest from the mid-1880s to the early 1900s caused White Sturgeon in the SSJ to decline to near extirpation.* (p897)

  Comment: The population likely reset itself after crashing more than a century ago under excessive harvest and habitat degradation. Its present state (see Figure 1) indicates a need for another reset. It is our opinion that such a reset can be accomplished with supplementation with conservation hatchery wild age-0 capture, supplemental rearing, and subsequent stocking in the Bay, accompanied by carefully managed hydrology and minimum harvest until population recovery.

- *Research conducted during the 1950s to 1980s designated the population as stable with sustainable harvest rates (Chadwick 1959; Kohlhorst 1980). Exploitation (μ) was estimated to vary between 2.0% and 7.3%, with most White Sturgeon caught as incidental bycatch by*

Striped Bass anglers (Pycha 1956; Miller 1972; Kohlhorst etal. 1991). However, enhanced technology (e.g., fish finders) and an increasing interest in the White Sturgeon sport fishery led to a μ of 11.5% by the late 1980s (Kohlhorst et al. 1991). As a result, several changes to White Sturgeon harvest regulations were implemented. For example, the CDFW designated a harvest slot limit of 117–183 cm TL in 1990 to protect mature White Sturgeon. Regulations continued to change throughout the 1990s and again in 2007 and 2013. Currently, anglers may harvest up to three White Sturgeon per year between 102 and 152cm FL. Despite increasingly restrictive harvest regulations, the potential for overexploitation of White Sturgeon in the SSJ remains a concern.

Comment: Adult sturgeon die-offs and other developments since this paper was published (during 2020-2023) indicate a need for stronger protections, at least in the near term. We recommend an annual harvest limit of one sturgeon and a daily catch-and-release limit of two sturgeon. Further gear, location, and seasonal restrictions may also be reasonable to minimize the effects from the sport fishery. The sport fishery provides important data in the management of the fishery and population, and thus is an essential part of the recovery program.

- *Rieman and Beamesderfer (1990) and Beamesderfer and Farr (1997) suggested that most North American sturgeon can only sustain levels of μ around 5%–10%. Additionally, current and historic estimates of μ for White Sturgeon are biased low because information on illegal harvest, total fishing effort, and total number of anglers is incomplete.* (p898)

  Comment: We agree. Given the state of the population, additional law enforcement effort should be considered, and a more comprehensive sport fishery management strategy and reporting system should be implemented. The added regulations and restrictions are likely to reduce fishing effort (i.e., total sturgeon fishing hours).

- *Recent results from several CDFW monitoring surveys suggest declining population trends. Since 1967, CDFW has intermittently conducted an adult sturgeon population study that monitors the relative abundance, distribution, exploitation, and growth of sturgeon in the SSJ. Since 1980, the CDFW has been monitoring White Sturgeon recruitment during sampling efforts from the San Francisco Bay Study (here- after termed the "Bay Study"). The Bay Study conducts monthly trawling surveys at fixed sites in the SSJ and the SFE to evaluate the effects of freshwater outflow on the abundance and distribution of fishes in the region (Fish et al. 2012). Catches of age-0 and age-1 White Sturgeon from the Bay Study serve as an index of recruitment. Although successful White Sturgeon recruitment in the SSJ has been documented as highly variable, data from the Bay Study suggest a decreasing trend in White Sturgeon recruitment since the mid-1980s, with undetectable recruitment during recent droughts (2007–2010 and 2012– 2016),*

  Comment: Such trends continue in the 2020-2022 drought and in wet year 2023 (see Appendix A).

  Population Statistics: (Figure D-1)

  Comment: We recommend a target goal of 5% harvest maximum while the population rebuilds (i.e., production in early recruitment years 5-10 increases) over the next decade. Data for this metric would be provided from the Trammel Net Survey that samples and estimates these year classes most effectively. ***(…**In particular, the capture efficiency of*

CDFW trammel nets may be ill-suited for sampling 200-cm FL and larger White Sturgeon. (p905)

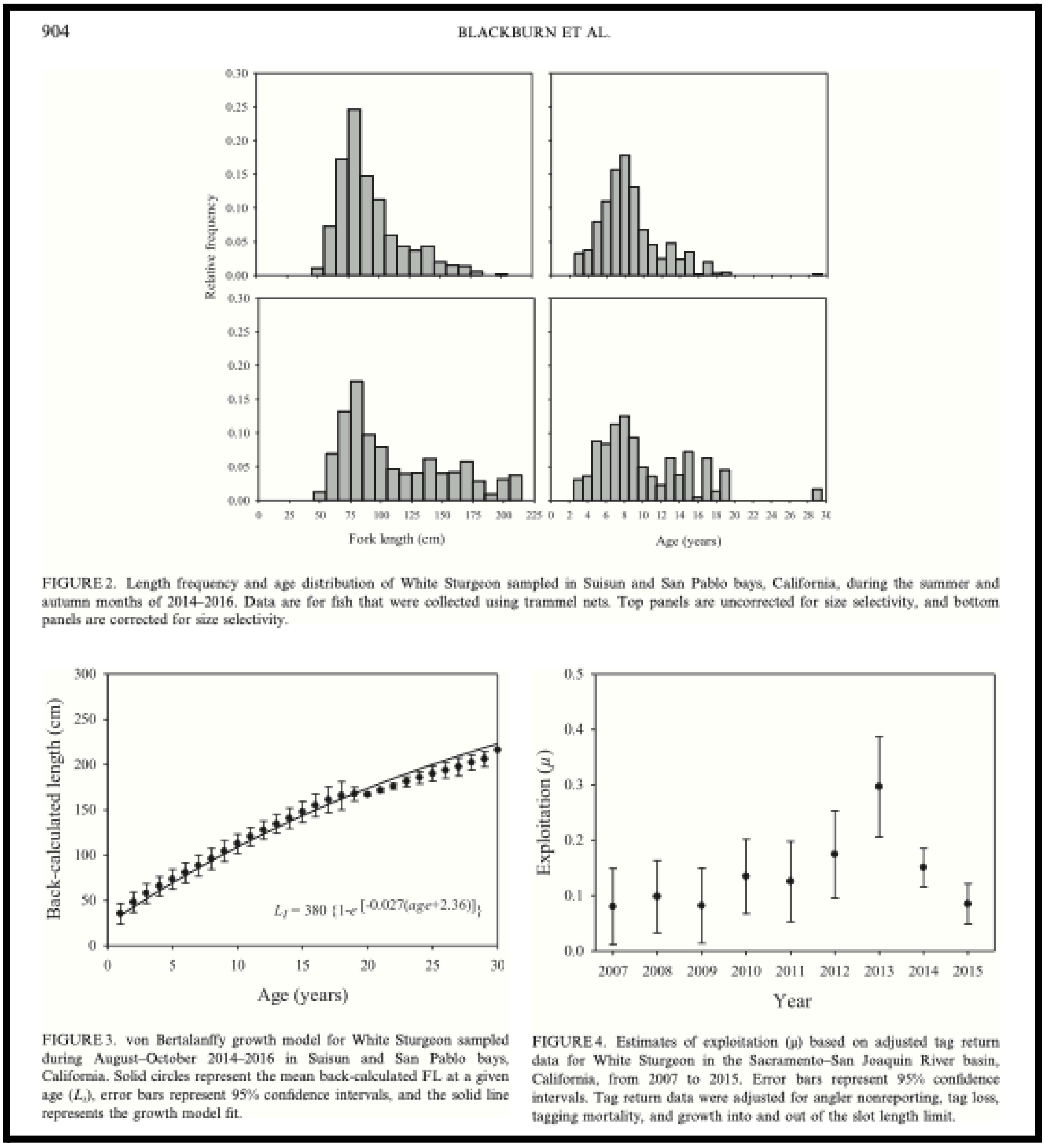
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FIGURE 2. Length frequency and age distribution of White Sturgeon sampled in Suisun and San Pablo bays, California, during the summer and autumn months of 2014–2016. Data are for fish that were collected using trammel nets. Top panels are uncorrected for size selectivity, and bottom panels are corrected for size selectivity.

FIGURE 3. von Bertalanffy growth model for White Sturgeon sampled during August–October 2014–2016 in Suisun and San Pablo bays, California. Solid circles represent the mean back-calculated FL at a given age (L_t), error bars represent 95% confidence intervals, and the solid line represents the growth model fit.

FIGURE 4. Estimates of exploitation (μ) based on adjusted tag return data for White Sturgeon in the Sacramento–San Joaquin River basin, California, from 2007 to 2015. Error bars represent 95% confidence intervals. Tag return data were adjusted for angler nonreporting, tag loss, tagging mortality, and growth into and out of the slot length limit.

Figure D-1. Population statistics.

- *Estimation of mortality for sturgeon populations is challenging due to uncertainties in the accuracy of aging techniques, different capture efficiencies between sampling gears, and difficulty in quantifying influences from anthropogenic activities.*

Comment: We propose focusing on the age 5-to-10-year recruitment and population estimates, supplemented with age-length information from other surveys.

- *The estimated mean annual μ (i.e., 13.6%) of White Sturgeon in the SSJ was higher than the 5–10% recommended to sustain sturgeon populations (Rieman and Beamesderfer 1990; Beamesderfer and Farr 1997). It is likely that our estimates of μ are biased low due to a low number of tag returns. The reason for low tag returns is unknown but could be due to low catch rates, inadequate publicity, an unwillingness of anglers to report their catch, or a combination thereof. Additionally, our estimate did not include illegal harvest or fishing mortality due to bycatch in other fisheries. Although the exact number of White Sturgeon that are illegally harvested in the SSJ is unquantified, the number is thought to be substantial (Gingras, unpublished information). Nevertheless, an absolute minimum μ estimate based solely on the proportion of tags returned was 8.0%.* (p907)

  Comment: We propose to reduce the effects of these biases with greater cooperation from the sport fishery in collecting data, combined with improved enforcement to reduce the illegal harvest. More comprehensive and unbiased population and harvest estimates will help.

- *Although conservation strategies include improving sturgeon spawning habitat (Schaffter 1997) and augmenting streamflow to mimic historic regimes (Jackson etal. 2016), reducing fishing mortality is likely the most effective, intermediate-term option for increasing the population abundance of White Sturgeon in the SSJ.* (p908)

  Comment: We disagree that fishing mortality should be the focus of the recovery effort. Impacts on recruitment such as poor habitat condition (water temperatures and flows) after spawning, water diversions, poaching, adult fish passage, and adult mass mortalities (i.e., Bay die-offs from hypoxia/red tide events), are each equally if not more important as factors related to potential extinction of the white sturgeon population.

- *Efforts that support decreasing the mortality of sexually mature White Sturgeon are further corroborated by results from the sensitivity analyses, which provide additional evidence that White Sturgeon are extremely vulnerable to exploitation. Our models indicated that under current harvest conditions, the survival rates of reproductive adults contribute the most to λ, followed by the survival of subadults. In populations that exhibit nonstable age distributions, such as White Sturgeon in the SSJ, high survival rates of sexually mature adults may be necessary to span lengthy gaps in recruitment (Gross et al. 2002). (p908)*

  Comment: The slot-limit fishery is designed to protect larger sexually mature white sturgeon. Reducing the upper end of the slot limit from 150 cm to 140 cm would place another abundant sexually mature age-size group under protection. Reducing annual harvest from three to one adults would provide further protection. Limiting the number of catch-and-release captures should also be beneficial. Eventually increasing recruitment into the spawning population of age-10 fish would provide further benefits. Gear, bait, season, and location restrictions in areas frequented by large sturgeon could provide further benefits over the long run. The greatest potential increase in adult spawner numbers would be from minimizing die-offs, stranding in the flood control system, and reducing or mitigating attraction to poor spawning-rearing habitats (e.g., the San Joaquin River). We also recommend rehabilitation of stressed-damaged adults captured in surveys in our proposed conservation hatchery. For example, fish stranded for long periods in flood bypasses could be rehabilitated and transported/released to the Bay.

E. LIFE HISTORY AND CURRENT MONITORING INVENTORY OF SAN FRANCISCO ESTUARY STURGEON. Heublein et. al. 2017. NOAA Technical Memorandum NMFS, SEPTEMBER 2017

- *This document describes life history and current monitoring of the two endemic sturgeon species of the San Francisco Estuary watershed: the southern Distinct Population Segment (sDPS) of North American green sturgeon green sturgeon and the Sacramento-San Joaquin River white sturgeon. It serves as background information used in the development of the conceptual models in Heublein et al. (2017). This document as well as Heublein et al. (2017) are fundamental in identifying existing and expanded monitoring needs necessary to track the status, trend, and viability of sDPS green sturgeon identified in National Marine Fisheries Service recovery planning efforts.* (p-iii)

  Comment: Life history monitoring information is useful in developing recovery actions for the species. Locations and habitat as well as habitat requirements and environmental tolerances are potentially important. The authors of this paper are highly knowledgeable of sturgeon science especially that of sturgeon population in the Central Valley. This paper provided the single most source of information that support the recommendations in this chapter to recover the sturgeon populations.

- *The majority of spawning for both species occurs in the mainstem Sacramento River; however, the downstream extent of sDPS green sturgeon spawning is approximately 80 kilometers (km) upstream of the typical spawning range of white sturgeon (Schaffter 1997; Poytress et al. 2015). Most sturgeon spawning in the SFE watershed occurs in spring, although white sturgeon can spawn earlier in winter, and green sturgeon spawning extends into early summer with periodic late summer and fall spawning.*
- *Spawning by both species typically occurs in areas that are deep and turbulent, but white sturgeon eggs occur in lower gradient reaches where channelized river habitat and fine substrate are common. There is no long-term monitoring of sturgeon spawning events (i.e., sampling for sturgeon eggs) on the Sacramento River. Recently, however, sturgeon egg sampling has occurred with some consistency in secondary spawning rivers (Feather and San Joaquin rivers).* (p-vi)

  Comment: It is safe to assume that sturgeon migrated far up the larger Central Valley watershed rivers as they did in the Columbia, Fraser, and Klamath rivers, but that large dams limits today's distribution. Large dams may also provide the necessary cool, clear tailwaters that attract spawning sturgeon (which may not have been present historically). Where such habitat exists, sturgeon are generally observed. Poor habitat conditions also explain why sturgeon no longer persist in rivers like the San Joaquin except in wet years.

- *With many of California's native fish subject to elevated and unsuitable water temperatures green sturgeon spawning in the upper Sacramento River is somewhat unique. Managed reservoir releases from Shasta Lake typically generate relatively low temperatures in the* *upper reaches of green sturgeon spawning and incubation habitat on the Sacramento River and maintain suitable temperatures even in extreme drought conditions.* (p-1)

Comment: It may be that conditions prior to the completion of Shasta Dam were better for green sturgeon, and that Shasta Dam and its associated water management have decreased the capacity of the river below the dam to produce both green sturgeon and white sturgeon. For example, in the middle reaches of the river below Shasta Dam, water temperatures are more a function of flow rates rather than input temperature from the dam. Dam storage of the winter-spring runoff may therefore lead to higher temperatures in some years, while summer dam storage releases may result in higher flows and lower water temperatures than occurred prior to the dam. Green sturgeon spawning success could be determined by both functions: providing adequate flow volume in winter-spring and summer.

- *In contrast, water temperatures that are suitable for normal egg development do not persist through the entire spawning and incubation period for white sturgeon in the San Joaquin River. Conditions on the Feather River in late spring and summer are also not appropriate for green sturgeon spawning and incubation in most years. This limitation to spawning habitat may become a more prominent issue if water temperatures continue to increase. Notably, spawning habitat in the upper reaches of the Sacramento River may provide sDPS green sturgeon resilience to climate change under a future scenario where most SFE sturgeon spawning habitats exceed optimal temperature ranges.* (p-1)

  Comment: Conditions in the middle Sacramento River are also unfavorable for white sturgeon in most years, which is why year class production is generally highest only in wet years and poor in other years. Year class production of white sturgeon can be improved throughout the Central Valley by improving spawning, incubation, rearing, and emigration conditions. Water temperatures continue to increase as a consequence of climate change and changes in water management. Green sturgeon spawning may not extend far enough upstream to benefit directly from cold-water releases from Shasta Reservoir, instead depending on flow releases from the dam that are more indirectly affected by climate change while controlled directly by water management (storage and release of water from Shasta Reservoir).

- *Coupling river conditions during sturgeon spawning and incubation with habitat requirements for egg and larval survival is a clear management consideration for both species. In laboratory studies, embryos of northern Distinct Population Segment (nDPS) green sturgeon and SFE white sturgeon have similar temperature optima and tolerances (see Fertilization to Hatch sections in this document for specific temperature ranges by species; Wang et al. 1985; Van Eenennaam et al. 2005). In this regard, management targets for spawning and incubation temperature may be similar for both species. In addition, river flows (which also influence water temperature) are heavily manipulated throughout the spawning ranges of both species. The direct effect of river flow magnitude and timing on spawning and incubation for both species remains uncertain. <u>There is an outstanding management need for a complete understanding of the effects of managed and unmanaged flow and temperature on SFE sturgeon spawning and incubation</u>.* (p-1)

  Comment: Flow and water temperatures are the main theme of our recommended recovery program for both sturgeon species. **<u>The seeming willingness of the resources agencies to ignore streamflow and water temperature requirements in the Sacramento River is the</u>**

single most important factor in the long-term decline of the river's two sturgeon populations. More on this subject later.

- *In laboratory studies, embryos of northern Distinct Population Segment (nDPS) green sturgeon and SFE white sturgeon have similar temperature optima and tolerances (see Fertilization to Hatch sections in this document for specific temperature ranges by species; Wang et al. 1985; Van Eenennaam et al. 2005). In this regard, management targets for spawning and incubation temperature may be similar for both species. In addition, river flows (which also influence water temperature) are heavily manipulated throughout the spawning ranges of both species. The direct effect of river flow magnitude and timing on spawning and incubation for both species remains uncertain. There is an outstanding management need for a complete understanding of the effects of managed and unmanaged flow and temperature on SFE sturgeon spawning and incubation.* (p-2)

  Comment: A large segment of the adult green sturgeon population appears to spawn above Red Bluff, where flows are controlled primarily by Shasta Dam operations with less influence from upper river tributaries; this influence wanes downstream in the white sturgeon spawning area in the middle reach of the river. It is generally acknowledged that white and green sturgeon eggs die or do not hatch if subjected to water temperatures above 68ºF/20ºC[1], and that white sturgeon spawn primarily between Knights Landing and Colusa (Figure E-1, water temperature in last decade at Wilkins Slough midway between the two locations). We have adopted the simple prescription of maintaining summer-fall (June-December) water temperatures in the middle and lower Sacramento River (below Red Bluff) at less than 68ºF/20ºC (the state water quality standard). In addition, we prescribe spring (March-May) water temperatures to be less than 60ºF at Red Bluff and less than 65ºF downstream to the mouth of the Feather River at Verona to protect sturgeon spawning and embryo development (consistent with the needs of salmon).

[1] https://www.noaa.gov/sites/default/files/legacy/document/2020/Oct/07354626440.pdf

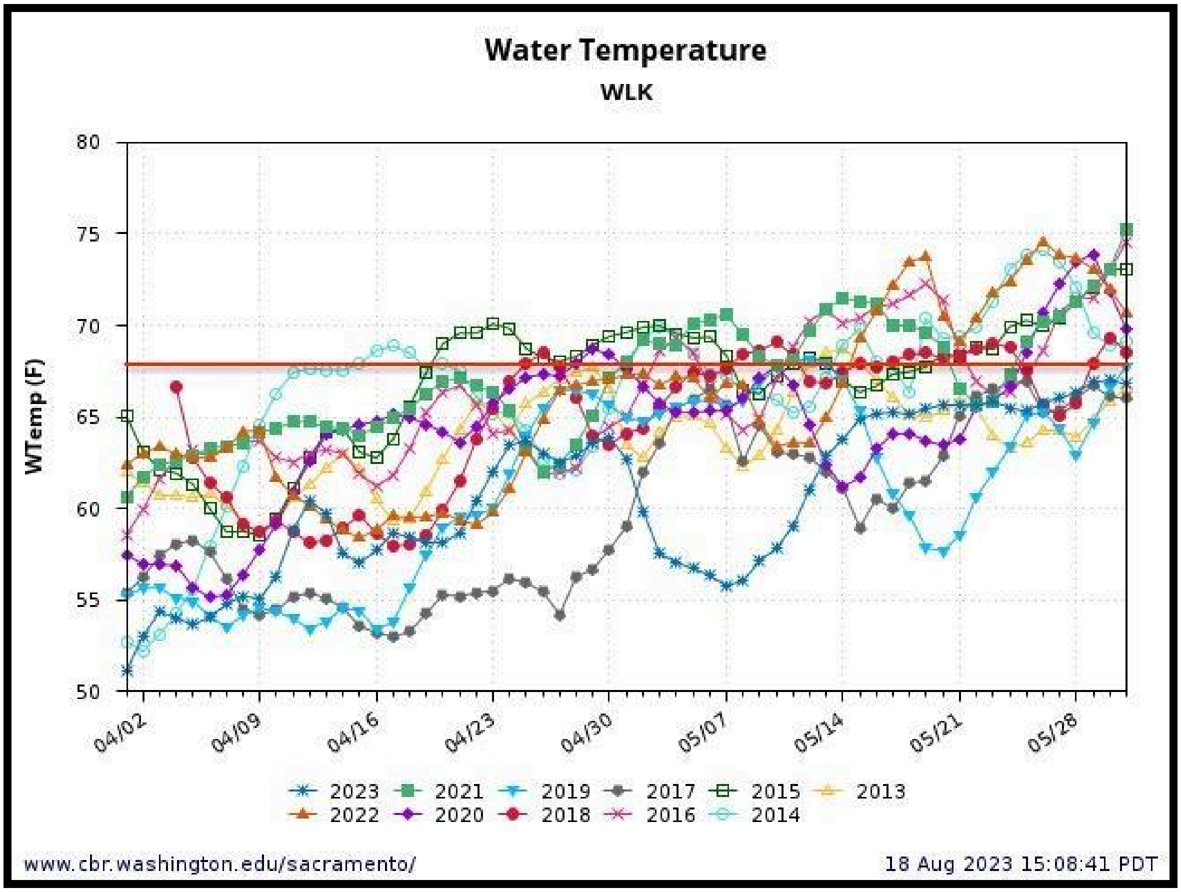

Figure E-1. Water temperatures in the Lower Sacramento River in April and May, 2013-2023. (Data source is DWR CEDC)

- *White sturgeon larvae may move into the freshwater estuary in spring and, as a result, would have access in some years to freshwater estuarine habitat and seasonally inundated wetlands. In contrast, sDPS green sturgeon larvae remain in riverine habitats until juvenile metamorphosis. This difference in larval distributions between species poses unique considerations for management of environmental conditions in their distinct habitats. Larval green sturgeon habitat in the upper Sacramento River is relatively stable due to flow and temperature management through operation of upstream dams and reservoirs. However, larval white sturgeon potentially utilize lower river and estuarine areas where conditions are more variable.* (p-2)

Comment: White sturgeon larvae rear in the Lower Sacramento River, showing up in the Delta as juveniles in early summer (Figure A-1). This pattern confirms the importance of the Lower Sacramento River and the North, Central, and Eastern Delta for white sturgeon larvae rearing and juvenile metamorphosis in May and June. Green sturgeon spawn farther upstream than white sturgeon. Larval green sturgeon develop in the upper river, where water temperatures are lower. Larval white sturgeon development is in the middle and lower river where waters are warmer, making them more vulnerable to hypoxia. "*During summertime, temperatures >20°C (68°F) amplify the effect of hypoxia on sturgeon"* (Secor and Niklitschek 2002). The fact that the Lower Sacramento River within and above the northern Delta is above 68ºF in drier years (Figure E-2) is the likely cause of poor dry-year white sturgeon age-0 production. The lower river channels also have more fine sediment that can dislodge the slightly adhesive eggs or bury them and deprive them of oxygen during incubation, thus maintaining the flows necessary to keep water temperatures lower and to ensure eggs are not buried by suspended sediment is important.

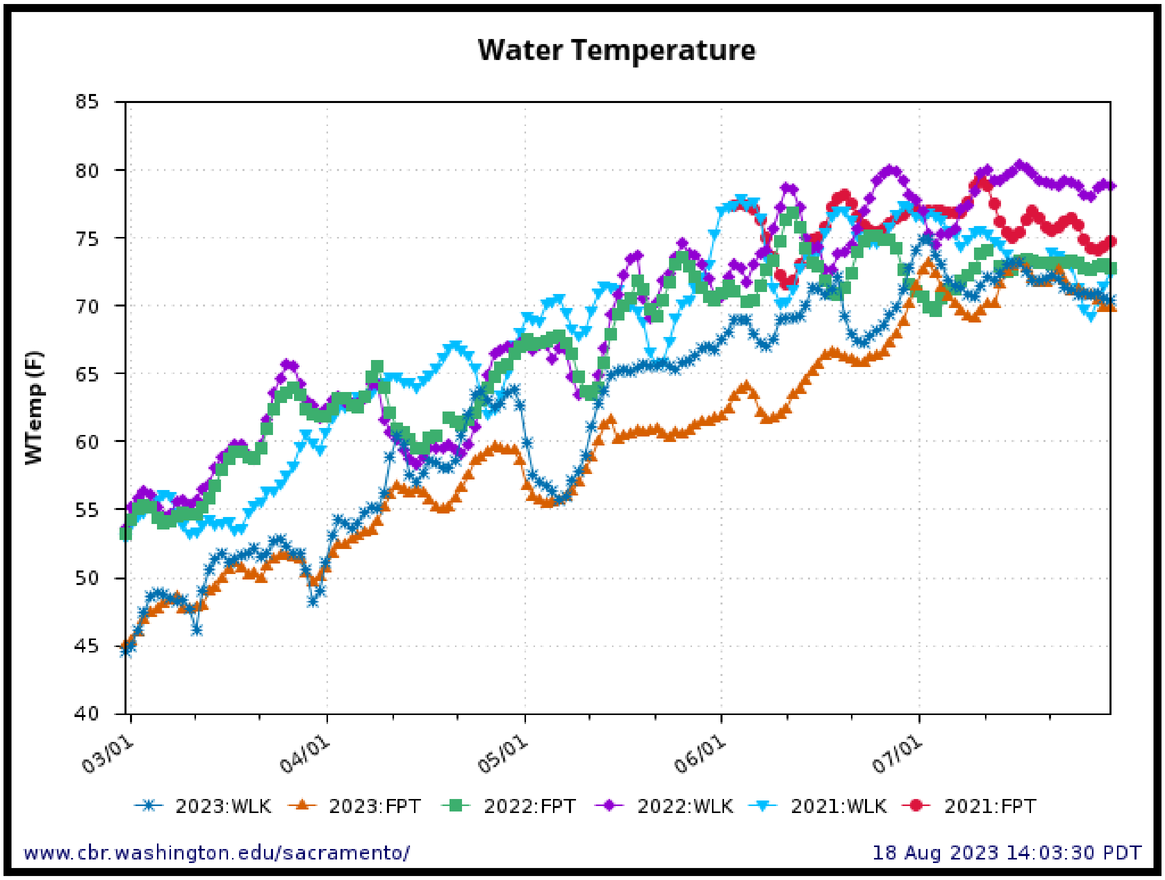

Figure E-2. Water temperatures at Wilkins Slough (lower Sacramento River) and Freeport (at entrance to Delta) gages 2021-2023. Our prescription for the lower Sacramento River through May is a maximum water temperature of 65ºF (18ºC) that along with the necessary higher flows best needs the needs of the young sturgeon.

- *Catch of small juvenile sturgeon of both species in the estuary is episodic with year-class successes likely occurring during wet years with elevated flow.* (p-2)

  Comment: Compared to salmon, larvae and juvenile sturgeon are smaller, more bottom oriented, and more prone to nocturnal migration, their movement toward the Bay-Delta estuary is more likely slower and less deliberate than juvenile salmon, thus they move better with the higher flow rates and river velocities of wetter years. In marginal flow years, with much of the precipitation stored in rim reservoirs, young sturgeon emigration rates likely suffer from natural-flow-reducing water project impacts. We have prescribed the spring flow pulse in the lower Sacramento River toward the needs of both the salmon and sturgeon emigration.

- *Juveniles of both sturgeon species have been found throughout the Delta.* (p-2)

Comment: Juvenile presence in the Delta is more likely in wetter years because of a higher likelihood of surviving to the Delta and better habitat conditions in the Delta. Note in Figure E-2 above that Freeport water temperatures were sustained through July at less than 72ºF, whereas in drought years 2021 and 2022 Freeport water temperatures reached 75-80ºF that are lethal to sturgeon. This is one of the primary reasons we have prescribed a maximum summer water temperature in the Interior Delta of 72ºF. (Note: high summer south Delta export rates result in many salmon, steelhead, Delta smelt, and sturgeon becoming "trapped" in the central and south Delta and unable to reach their normal nursery areas to the west. The higher export rates of wetter years require maintaining better conditions in the Delta especially in wetter years.)

- *Juvenile green and white sturgeon are rarely caught in estuarine monitoring surveys; in many years, juvenile sDPS green sturgeon are absent from all monitoring. Data from juvenile white sturgeon sampling in the estuary is used to generate a coarse recruitment index and forecast of adult cohort abundance (Fish 2010). Although increasing juvenile collection of both species may be challenging, these potential data are critical to understanding environmental factors influencing juvenile sturgeon recruitment and establishing necessary early life stage abundance measures for sDPS green sturgeon.* (p-3)

  Comment: Because juvenile sturgeon are benthic oriented (bottom dwellers), they are not likely captured in standard river and Bay-Delta surveys other than the Bay Otter Trawl Survey. We are recommending reverse screw trapping bottom sampling in river and Delta channel locations to capture sturgeon juveniles. We also recommend continuing the Bay Otter trawl survey as well as Delta pumping plant salvage monitoring.

- *Adult white sturgeon are found throughout the year in brackish areas of the SFE, and individuals tagged in the SFE are rarely detected or recaptured in marine areas or non-natal estuaries (Kohlhorst et al. 1991).* (p-3)

  Comment: This characteristic makes the white sturgeon population especially vulnerable to summer Bay-Delta estuary conditions that periodically result in warm water with accompanying algae blooms and dissolved oxygen levels below 50% saturation and 6 mg/l that may lead to sturgeon die-offs during drought and wet years. Such events are a serious threat to the white sturgeon population. Our recommendations include measures to minimize this threat.

- *White sturgeon are the more common and abundant sturgeon species in the SFE and support a large sport fishery. Thus, directed sturgeon sampling studies and fishery-dependent monitoring in the SFE watershed are focused predominantly on white sturgeon. While disproportionate catch may suggest habitat segregation between species in the SFE, directed sampling of adult green sturgeon in the SFE has almost always involved catch of both species (M. Holm 2016, personal communication, see "Notes"). In this regard, green and white sturgeon most likely occupy similar areas within the SFE.*

  Comment: While their distributions and habitat preferences appear to overlap, their occupancy of the Delta, Bay, and ocean appears to differ significantly, which makes their vulnerabilities and ecological requirements different in scale and magnitude. White sturgeon appear more at risk in the rivers, Delta, and Bay.

- *juvenile SFE sturgeon are rarely encountered, and larval SFE sturgeon are only collected incidentally in studies directed at other species and are typically too small for non-lethal tissue analyses. Ongoing monitoring of adult sturgeon in the SFE and associated studies (e.g., population modeling, tagging, analysis of genetics and contaminants) presents an opportunity to increase understanding of both species.* (p-3)

  Comment: Larval sturgeon are found mainly in the lower rivers in spring. Juvenile white sturgeon, however, concentrate in the Delta by late spring and in summer (see Figure 5, Figure E-3), where habitat conditions are generally poor (e.g., water temperatures exceed 75ºF in drier years). Although juvenile sturgeon are generally more tolerant than larvae or adults of harsh habitat conditions, temperatures higher than 25ºC/77ºF are not tolerated and stress is observed as temperatures approach or exceeds 20ºC/68ºF (Cech et al. 1984, Geist et al. 2005). Monitoring of larvae in rivers, juveniles in the Bay-Delta, and adults in Bay-Delta and rivers should be upgraded to provide the "…*increased understanding of both species'*…" distributions, abundance, and habitat conditions.

- *Both green and white sturgeon are susceptible to stranding at the Sutter and Yolo Bypass Weirs during the same hydrologic conditions and timing.* (p-3)

  Comment: Winter-spring storms can result in the Sacramento River spilling over weirs into flood bypasses, attracting adult sturgeon to the bypass outfalls; this can subsequently lead to their stranding below the weirs (Figures E-4, E-5, and E-6). Large numbers of white sturgeon have also been captured in Yolo Bypass internal weirs (e.g., Lisbon Weir) as well as isolated ponds.

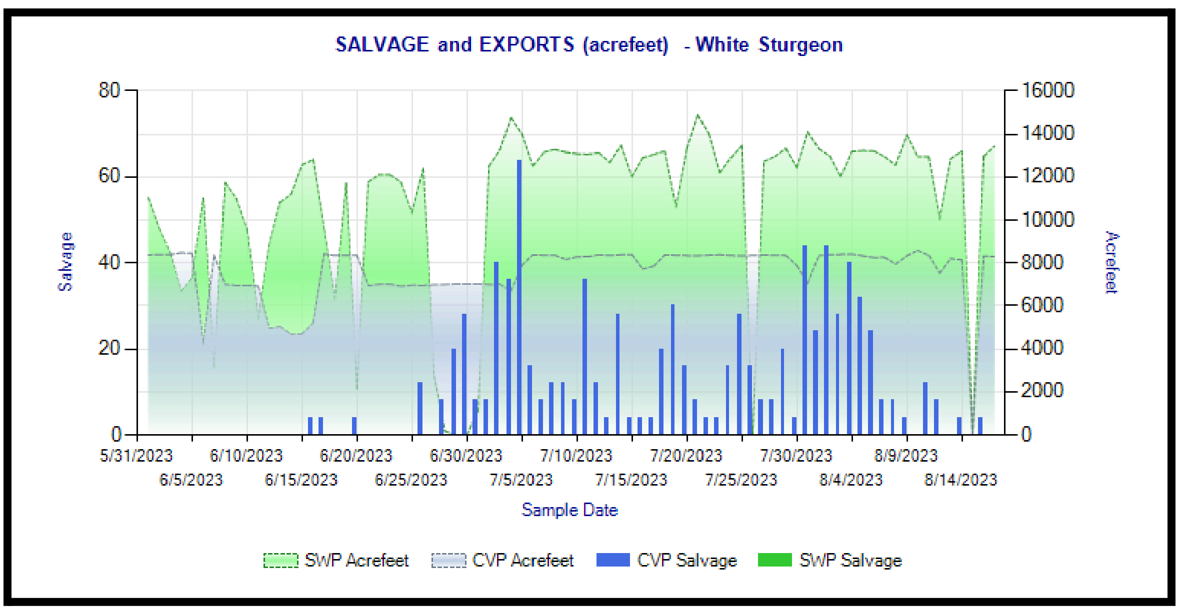

Figure E-3. Salvage of juvenile white sturgeon at south Delta export fish facilities summer, 2023. Note maximum export rates (22,000 acre-ft/day; 11,000 cfs) in July. Historical catches were similar at the two fish facilities, therefore lack of salvage at the SWP can be attributed to the source of the fish being the San Joaquin River via the Head of Old River.

Figure E-4. Spill over of the Moulton Weir from the Sacramento River into the Sutter Bypass in winter, 1997. Adult sturgeon enter (are attracted to) the lower exit of the bypass and are then blocked by the weir as they attempt to return to the Sacramento River.

Figure E-5. Stranded sturgeon rescued by CDFW staff below the Fremont Weir in the Yolo Bypass. CDFW staff have observed stranded, dead, and poached sturgeon in the Yolo Bypass in years when spills occur.

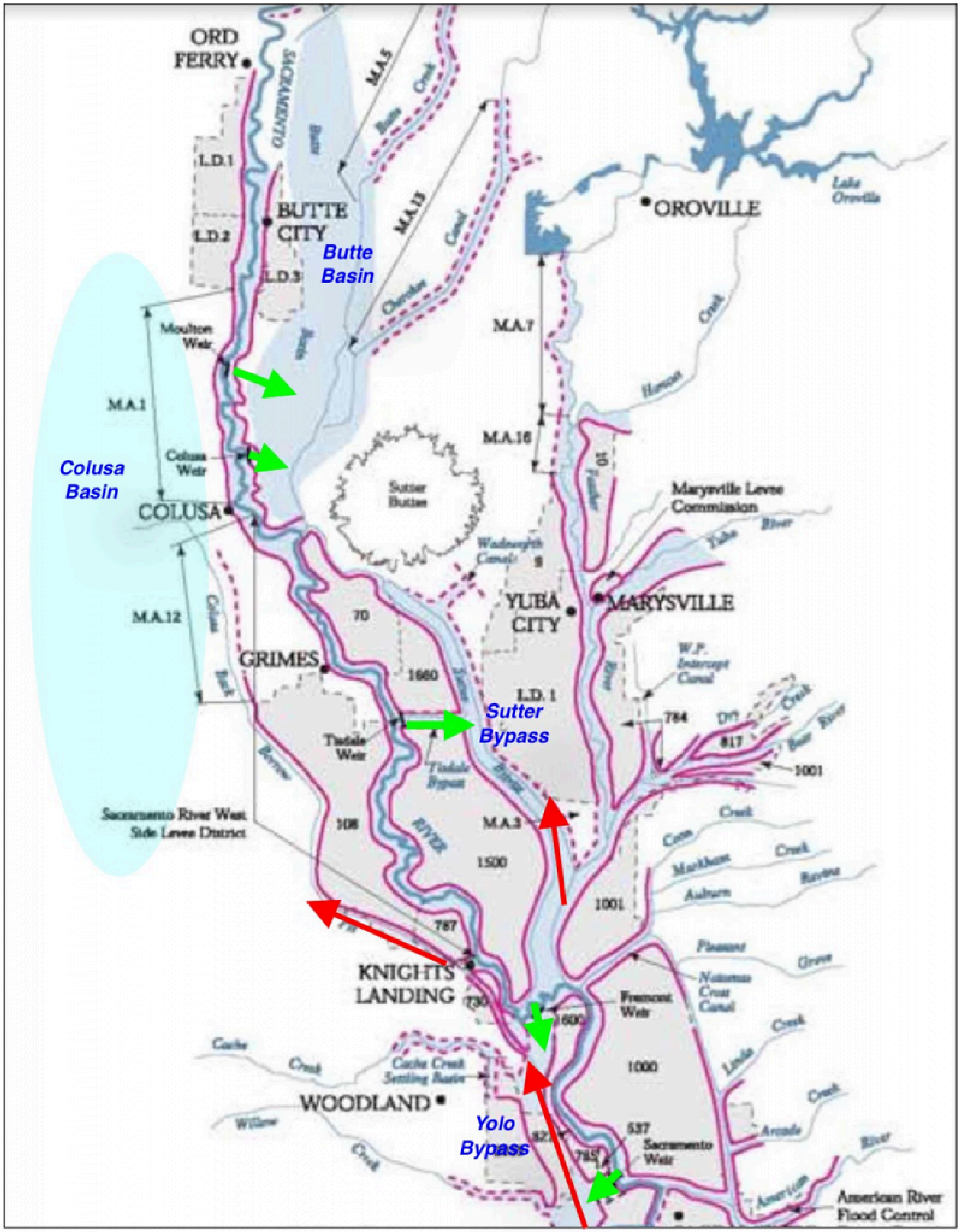

Figure E-6. Map of the Sacramento Valley showing levees and flood control system weirs and bypasses. Gray area agricultural basins are generally below the elevation of the river and bypasses. The flood control system was initially designed to convey flood water and historic foothill mining debris through the Valley to the Bay-Delta. Adult salmon (as well as sturgeon and steelhead) are attracted to the high flows entering, passing through, and exiting the Sutter and Yolo Bypasses. (Adult migration is shown with red arrows.) Many of the fish cannot successfully complete their passage, either becoming lost or blocked at the upstream end by weirs (located at the blunt end of the green arrows).

- *The observed spawning habitat partitioning on the Sacramento River most likely indicates different preferences for spawning substrate or other habitat attributes between species (e.g., channel gradient and velocity). Both species show a variety of post-spawn migration and holding behaviors, but it is more common for post-spawn green sturgeon to hold for a few months or more in freshwater habitats and for white sturgeon to return to the SFE immediately after spawning (Heublein et al. 2009; Klimley et al. 2015).* (p-3, 4)

  Comment: White sturgeon spawn closer to the Delta in spring. Their larvae probably develop over the spring and summer in the lower rivers and in the Delta. As stated above, the juveniles concentrate in the Bay and Delta (see Figure E-3) during summer. We recommend a spring pulse flow in the San Joaquin and Sacramento Rivers to support all larval, fry, and juvenile anadromous fish migration into and through the Delta to the Bay.

- *There is no directed monitoring of the white sturgeon spawning run on the Sacramento River beyond angler catch reporting in spawning reaches. Recently, directed study of spawning sturgeon has occurred on the San Joaquin River (white sturgeon) and, to lesser extent, the Feather River (primarily green sturgeon). White and green sturgeon migrating to spawning habitat in the Sacramento and Feather rivers are periodically sampled at the Sutter and Yolo Bypass Weirs, and white sturgeon are collected in general fish community monitoring in the Yolo Bypass. Annual spawning measures (e.g., annual run-size, spawning distribution, verification of successful spawning) are fundamental metrics necessary for management of both sturgeon species. Monitoring of spawning sturgeon should be expanded such that these metrics are uniformly available throughout the spawning ranges of both species.* (p-4)

  Comment: We agree. We have included monitoring of sturgeon at proposed segregation weirs and in Bay-Delta mark-recapture assessments.

- *Sturgeon early life history sampling has been conducted in the Feather River since 2011 with egg mats and intermittent D-net sampling (Seesholtz et al. 2015; A. Seesholtz, DWR, 2017, unpublished data, see "Notes"). Sturgeon have never been collected in rotary screw traps in the Feather River. Spawning on the Feather River has been confirmed in only two locations: below Fish Barrier Dam, which is a barrier to anadromous fish passage, and 13 km downstream at the outlet of the Thermalito Afterbay (Thermalito Outlet). Seesholtz et al. (2015) estimated that spawning at the Thermalito Outlet occurred from June 12 through 19, 2011, when water temperatures were 16 to 17°C, whereas spawning occurred in substantially cooler temperatures at FishFish Barrier Dam (approximately 11°C) in late May or early June 2017 (M. Manuel, PSMFC, 2017, personal communication, see "Notes").* (p-8)
- *Van Eenennaam et al. (2005) exposed the fertilized eggs of one nDPS female to six temperature regimes (11, 14, 17, 20, 23, and 26°C). **Egg survival to hatch was highest in the 14°C and 17°C treatments** (39% and 36%, respectively), with **total mortality at temperatures of 23°C and above** (Van Eenennaam et al. 2005). Van Eenennaam et al. (2005) also found a decreased hatching rate in the 11°C treatment compared to 14°C, but the lower temperature limit for embryo survival was not determined. Elevated water temperature can cause deformities in embryos. **The proportion of hatched embryos with deformities was relatively high at 17°C and 20°C** (10.3% and 51.6%, respectively) and low at 11°C and 14°C treatments (3.7% and 1.2%, respectively; Van Eenennaam et al. 2005). Based on this information, **Van Eenennaam et al. (2005) concluded temperatures less than 17.5°C are optimal for normal development of embryos (Table 3)***. (p-9)

Table 3. Green sturgeon temperature tolerances by life stage.
Laboratory studies involving nDPS green sturgeon from Klamath River broodstock (a, b, c, d, dd, f) were used to rate water temperatures for the eggs, larvae, and juveniles. Water temperatures recorded during sDPS green sturgeon egg and larvae collection on the upper Sacramento and Feather rivers (e, g, and h) were used to establish "acceptable temperature" for spawning adults and larvae. Categorization of temperature tolerance is not directly comparable at upper and lower levels in this table because "impaired fitness" may be related to both indirect sources of mortality (e.g., reduced growth rate) and direct sources of mortality (e.g., increased rate of deformities). a = Mayfield and Cech 2004; b = Van Eenennaam et al. 2005; c = Werner et al. 2007; d = Allen et al. 2006; e = Poytress et al. 2012; f = Linares-Casenave et al. 2013; g = Poytress et al. 2015; h = Seesholtz et al. 2015; and dd = Allen et al. 2006b.

temperature °C	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
temperature °F	46.4	48.2	50.0	51.8	53.6	55.4	57.2	59.0	60.8	62.6	64.4	66.2	68.0	69.8	71.6	73.4	75.2	77.0	78.8	80.6	82.4
egg				b	b	b	b	b	b	b	b	b	b	b	b,f	b,f	b,f	b,f	b,f	b	b
larvae							e	e	e	c	f	dd,f	dd,f	dd,f	dd,f	dd,f	dd,f	dd,c,f	f	f	f
juvenile				a	a	a	a	a	a	a	a	a	a	a	a	a	a,d	a	a	a	a
spawning adult			g	g	g	g	g	g	g,h	g,h											

(green)	optimal temperature
(yellow)	acceptable temperature
(orange)	impaired fitness; avoid prolonged exposure; increasing chance of lethal effects
(red)	likely lethal
(black)	lethal
(light blue)	unknown effect upon survival and fitness

Comment: We recommend maintaining habitat conditions conducive to larval sturgeon survival in the Lower Feather River spawning reach from May through July; similar conditions should be maintained for rearing juvenile sturgeon from July through September. These same conditions would apply to other tributaries (and the Upper Sacramento River above Hamilton City) for spawning green sturgeon. See Figure E-7 for our recommendation. Adult winter-spring migrating, holding, and spawning temperatures should not exceed 65ºF (18ºC).

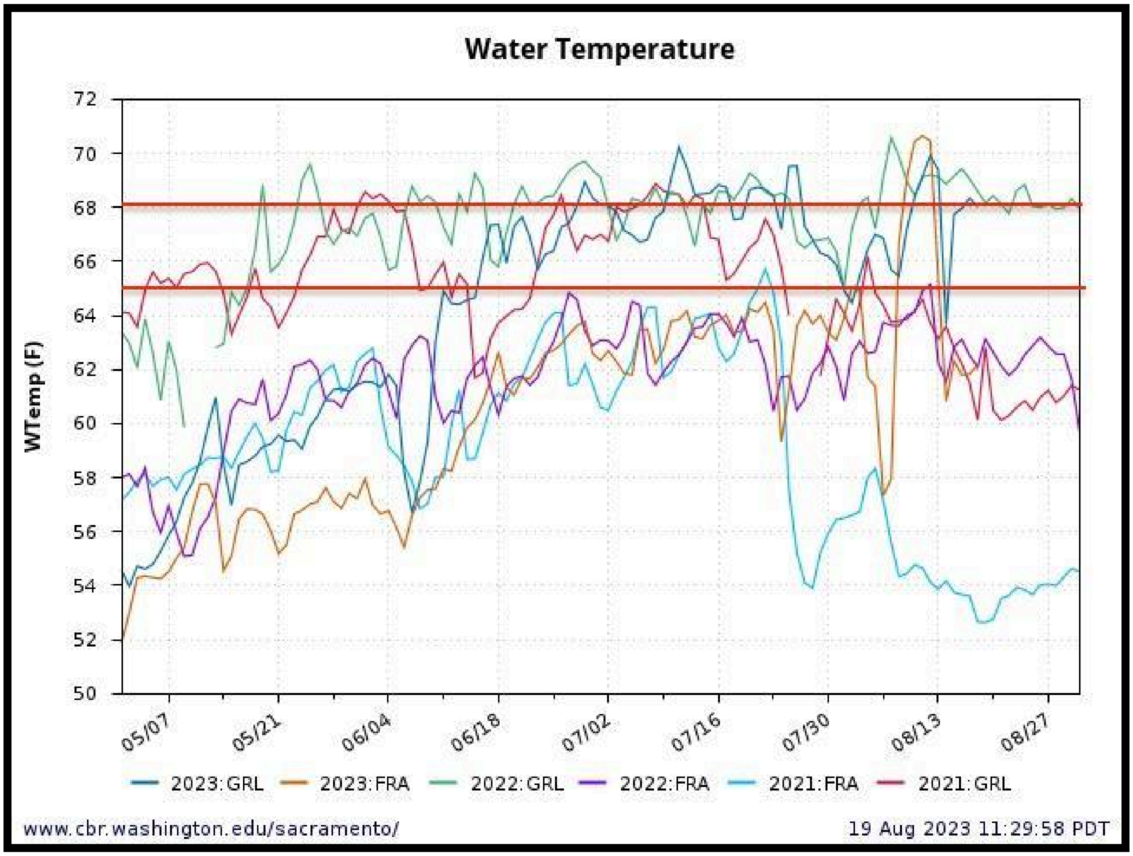

Figure E-7. Water temperature below the Feather River Fish Barrier Dam (FRA) (spawning reach) and at Gridley (GRL; rearing reach) below the Thermolito Outlet in spring-summer of 2021, 2022, and 2023. Red lines denote our recommended maximum temperatures for spring and summer at FRA (lower line) and at GRL (upper line). Note that the spring and summer of drought years 2021 and 2022 had frequent temperatures at GRL above the recommended 68°F.

- *optimal temperatures for sturgeon egg incubation (below 17°C) extend downstream to RBDD in spring and summer of most years, but typically remain below laboratory-based optima for egg incubation upstream of existing spawning and egg incubation areas (closer to Keswick Dam). In downstream areas closer to GCID* (Hamilton City)*, water temperatures are typically* ***suboptimal for incubation in the late spring and summer (above 17.5°C)****. During periods of extremely low reservoir storage and outflow, incubation temperatures may be suboptimal in the late spring and summer near RBDD and* ***approach potentially lethal temperatures (above 20°C)*** *in areas closer to GCID.* (p-11)
- *The SFE white sturgeon spawn primarily in the mainstem Sacramento River and to a lesser extent in the San Joaquin River in late winter and spring. Based on collection of gravid adults, spawning also periodically occurs in other rivers (e.g., the Feather and Bear rivers) in the Sacramento River basin. There is no long-term monitoring of white sturgeon eggs in the Sacramento River, but egg distribution is likely similar to the putative spawning reach, which typically ranges from just upstream of Colusa (rkm 252) to near Verona (rkm 129; Kohlhorst 1976; Schaffter 1997)*. (p-11)
- *In the Sacramento River, white sturgeon typically spawn between February and June. Tagged adult white sturgeon move from the SFE to spawning reaches of the Sacramento River*

between mid-February and early June (Miller 1972; Schaffter 1997; E. Miller UCD Biotelemetry Laboratory, 2017, unpublished data, see "Notes"). Kohlhorst (1976) used D-nets to collect white sturgeon eggs and larvae as early as mid-February, with the majority (93%) collected in March and April. Schaffter (1997) collected eggs in the Sacramento River on artificial substrates from March through May. Angler reporting of tagged adults in spawning habitat coincident with early season flow events also indicates migration and possibly spawning occur in December and January in some years (CDFW, 2016b, unpublished data, see "Notes"). (p-12)

Comment: We recommend maintaining water temperatures in the white sturgeon spawning reach from Colusa downstream to Knights Landing at 65ºF in the April-May peak spawning period, and 68ºF in the summer larvae-juvenile rearing and adult emigration (return) period (Figure E-8). This is consistent with our salmon recommendations (see Sacramento River Fall Run Salmon chapter).

- *Brown (2007) discovered larvae in the upper Sacramento River at Bend Bridge (rkm 415), and spawning has been confirmed as far downstream as the GCID facility (Poytress et al. 2015), suggesting that larvae occupy over 100 km of the Sacramento River. Due to the limited number of larval collections, the upstream egg distribution described above (Sacramento River to Cow Creek and Feather River to Fish Barrier Dam) is also applied to larvae. Larval sturgeon distribution may range well downstream from spawning habitat. Larval white sturgeon and unidentified larval sturgeon have been collected more than 100-km downstream from known white or sDPS green sturgeon spawning areas during the 20mm Survey and in salvage at the Tracy Fish Collection Facility and John E. Skinner Fish Protection Facility near federal and state Delta pumping facilities (CDFW, 2016a, unpublished data, see "Notes"). Thus, larval distribution is estimated to extend at least 100-km downstream from spawning habitats on the Sacramento and Feather rivers in high flow years. This estimated downstream distribution corresponds with the Colusa area on the Sacramento River (rkm 252) and the confluence of the Sacramento and Feather rivers near Verona (rkm 129) for larvae originating in the Sacramento River and Feather River, respectively.* (p-14)

  Comment: These finding support our recommendation for spring 65ºF upper water temperature limit in the lower Sacramento River as well as spring pulse flows.

- *Larval abundance and distribution may be influenced by spring and summer outflow. There appears to be a positive relationship between annual outflow and larval abundance in the RBDD rotary screw traps; RBDD rotary screw trap collections of larval green sturgeon were far greater in the three most recent wet years1 (2011, 2016, and 2017) since the monitoring began in 1995 (W. Poytress, USFWS, 2015a, unpublished data, see "Notes"). Moreover, green sturgeon eggs and larvae were only collected during wet years (2011 and 2017) on the Feather River (Seesholtz et al. 2015; M. Manuel, PSFMC, 2017, personal communication, see "Notes").* (p-14)

  Comment: Our recommended spring pulse flow and general flow requirements for the upper river between Keswick Dam and Red Bluff should benefit juvenile green sturgeon recruitment in the upper river spawning and incubation reach. Flow and water temperature benefits should extend downstream below Colusa to benefit white sturgeon recruitment.

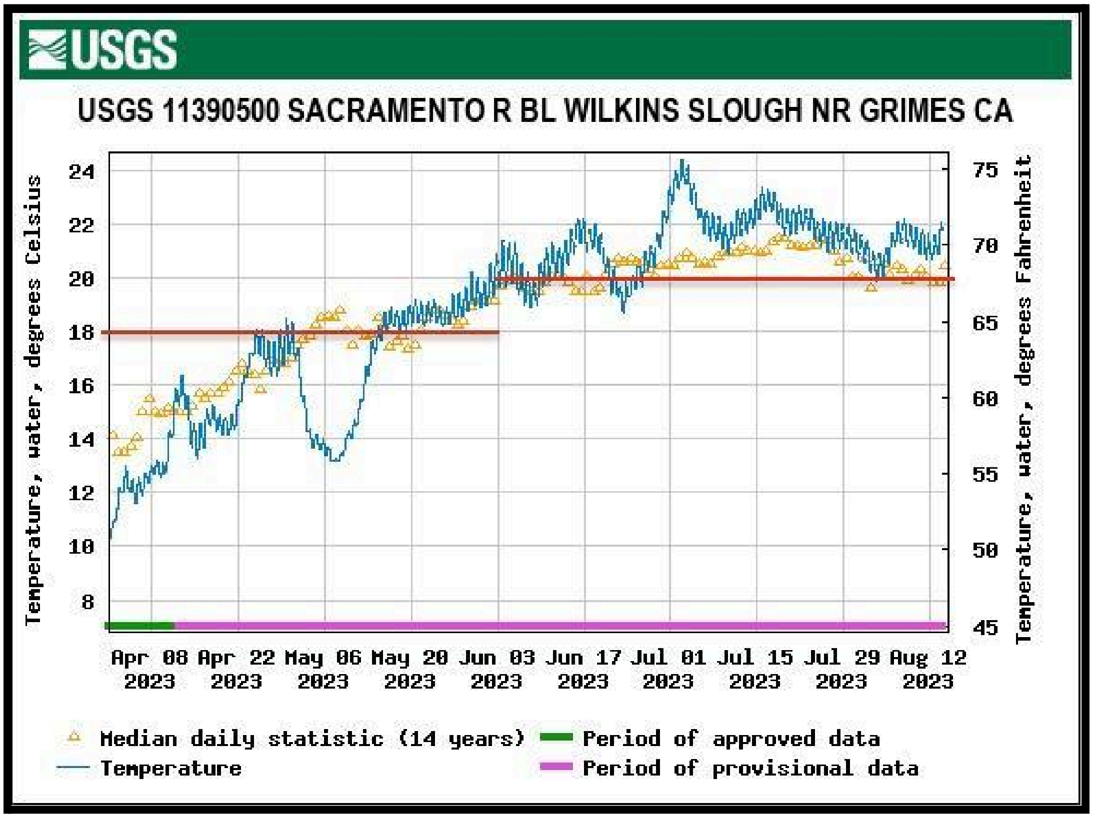

Figure E-8. Water temperature at Wilkins Slough midway between the Colusa and Knights Landing white sturgeon spawning reach in 2023, with the mean for the past 14 years. The state water quality standard for the reach is 68ºF maximum.

- *Potentially optimal water temperatures for larval growth near RBDD could correspond to low concurrent spawning production and egg survival. Furthermore, warmer water temperatures near RBDD could be associated with poor survival of early life stages of green sturgeon in lower reaches of Sacramento River spawning habitat and SRWC closer to Keswick Dam.* (p-15)

  Comment: Our recommended water temperature for Bend Bridge/Red Bluff in spring is an upper limit of 60ºF to protect juvenile salmon. We also recommend 60ºF as it falls within the optimal range of larval green sturgeon growth of 60-65ºF. Our recommendations ensure that the optimal range occurs from the spawning reach above and below Red Bluff to and through the lower river accommodates juvenile salmon and steelhead, adult spring run and winter run salmon runs, and spawning and rearing green sturgeon and white sturgeon. (For more detail on this topic see discussion associated with Figure 59 of the Sacramento Fall Run Salmon Chapter.)

- *Juvenile green sturgeon entrainment in the presence of unscreened water diversions (Mussen et al. 2014) and diversions with fish protection devices (Poletto et al. 2014a, 2014b, 2015) have been studied extensively in the laboratory. These studies suggest juvenile green sturgeon are at high risk of entrainment in unscreened diversions and impingement on screened diversions. Furthermore, Vogel (2013) captured four green sturgeon and one white sturgeon during evaluation of fish entrainment at 12 unscreened diversions in the middle Sacramento*

River. Verhille et al. (2014) reported larval and juvenile green sturgeon swimming performance and flow velocity recommendations for diversions by life stage; however, fish screen design criteria specifically for larval sturgeon have not been developed. (p-17)

Comment: We recommend limiting South Delta exports through early summer (June-July) per D-1485 requirements. Those requirements recognized the negative effects of South Delta exports in June and July to spring-spawning native and non-native fishes. Those restrictions were removed in D-1641 in favor of E/I ratios and OMR restrictions, which proved ineffective.

- *Juvenile white sturgeon are believed to initiate a secondary dispersal (the primary dispersal occurring at the larval stage) in spring by actively swimming downstream during the night (Kynard and Parker 2005). Dispersal duration is unknown, but observed swimming intensity and duration in laboratory studies indicate dispersal likely lasts several days and over many kilometers (Kynard and Parker 2005).* (p-17)
- *Radtke (1966) indicated that juvenile white sturgeon are found in the Sacramento River and Delta, with the majority of juveniles captured in the Sacramento River.* (p-18)

Comment: This larval dispersion strategy would likely benefit from the spring pulse flow we prescribe for the Sacramento and San Joaquin Rivers. The dispersion pattern ends up with larval white sturgeon concentrated in the lower river from about Knights Landing into the North and Central Delta in early summer. That dispersion is represented in Figure E-3, which illustrates the effects the export pumps exert on juveniles by pulling them into the South Delta in early summer. This pattern may also be indicative of spawning in the San Joaquin River in wet years (as mentioned earlier).

- *Indices of recruitment, or year-class index (YCI) have been generated by otter trawl catch of age-0 and age-1 white sturgeon in the Bay Study since 1980. Recruitment trends in the YCI are supported by back-calculation of recruitment with direct or assigned estimates of age (e.g., age analysis of pectoral fin rays or use of age-length keys) from collections of white sturgeon by various monitoring studies. CDFW and USFWS continue to develop those recruitment-modeling techniques by refining estimates of age at length, gear selectivity, and mortality rates.* (p-18)
- *A positive relationship between high outflow and white sturgeon recruitment in the SFE is supported by juvenile surveys (CDFG 1992; Fish 2010) and hind-cast estimates of relative brood-year abundance from adult monitoring studies (Shirley 1987; M. Gingras, CDFW, 2015a, unpublished data, see "Notes"). Recent investigations show a Delta outflow-recruitment threshold at about 1,416 cubic meters per second (m3/s;* ***<u>50,000 cubic feet per second), such that the juvenile YCI is generally strong when flows are above that level</u>*** *(Fish 2010). Cohort abundance information since 1938 shows a boom-and-bust pattern that appears to be related to those high outflow periods (Shirley 1987; CDFG 1992; Fish 2010). Large white sturgeon cohorts have only been detected twice in the last 20 years—in 1998 and 2006—and both years were classified as wet (CDFW, 2016b, unpublished data, see "Notes"). It should be noted, however, that the primary white sturgeon recruitment survey (Bay Study) was incomplete in 2016 and 2017; indexes have not been generated since 2015.* (p18-19)

Comment: These estimates of recruitment (see Figure 4) are crude at best. We recommend expanding the age-0/age-1 Otter Trawl Survey along with other sampling mechanisms to provide a stronger "more refined" index with better distribution and mark-recapture elements.

Such estimates would more accurately identify factors that affect age-0 recruitment, relating them with greater accuracy to mark-recapture estimates of older age groups sampled in adult surveys and the sport fishery. If strong year classes only occur in wet years, what wet year characteristics are specifically missing from the drier years?

- *it is difficult to generate fishery-dependent sDPS green sturgeon harvest and abundance estimates in the SFE from those data beyond applying a rough assumption of the percentage of sDPS green sturgeon in the overall sturgeon population. A major challenge in estimating abundance and overall harvest of sDPS green sturgeon has been mixed aggregations of nDPS and sDPS green sturgeon in Oregon and Washington estuaries and historical harvest in commercial and recreational fisheries in those estuaries.*

  Comment: We recommend more comprehensive adult sturgeon monitoring with an expanded trammel/trap net survey and tagging program and expanded data collection in the sport fishery. A comprehensive conservation hatchery program combined with PBT-type tissue collection and analysis would benefit this objective for both white and green sturgeon.

- *The Oregon Department of Fish and Wildlife (ODFW) and Washington Department of Fish and Wildlife (WDFW) conducted a large-scale (approximately 1,500 green sturgeon tagged) mark-recapture study to estimate the population size of subadult and adult green sturgeon (described in NMFS 2015). That study generated a wide range of population estimates for adult and subadult green sturgeon (approximately 4,000 to 65,000 fish) in Oregon and Washington estuaries; the authors of that study concluded that an estimate of 40,000 fish was reasonable (NMFS 2015). Genetic analysis by Schreier et al. (2016) revealed 60% of sturgeon tissues collected in this study were from sDPS green sturgeon. Using estimates of annual run-size and spawning periodicity, Mora (2016) estimated the number of sDPS adults to be 1,990 (95% confidence interval [CI] is equivalent to 1,172 to 2,808 adults). Mora (2016) also applied a conceptual demographic structure to that adult population estimate and estimated a sDPS subadult population of 10,450 (95% CI is equivalent to 6,155 to 14,745). The population dynamics inferred in these studies—along with relatively low collection numbers of green sturgeon in SFE surveys—**suggest the majority of the sDPS subadult and adult population occupies non-natal estuaries during summer months**.*

  Comment: This study is very important because it demonstrates that Sacramento River age-0/1 recruitment may be the most critical population recovery factor of the sDPS green sturgeon. It also indicates that the sDPS green sturgeon spawning stock in the Sacramento River may be higher than previously thought – the adults live in the ocean and non-natal estuaries. The total population may be on the same level as white sturgeon, which would make the white sturgeon population with adults residing in the Bay-Delta more at risk than the green sturgeon.

- *Daily and seasonal movement of adult white sturgeon may be influenced by salinity and tides. Kohlhorst et al. (1991) found that white sturgeon followed brackish waters upstream in dry years and remained downstream in the SFE in wet years. Foraging movements of white sturgeon in the Columbia River Estuary were also influenced by diel cycles and salinity changes associated with tides (Parsley et al. 2008).* (p-22)

  Comment: This pattern points out the risk to white sturgeon from warm conditions (>20ºC,68ºF) in the Bay-Delta in any water year type (Figure E-9).

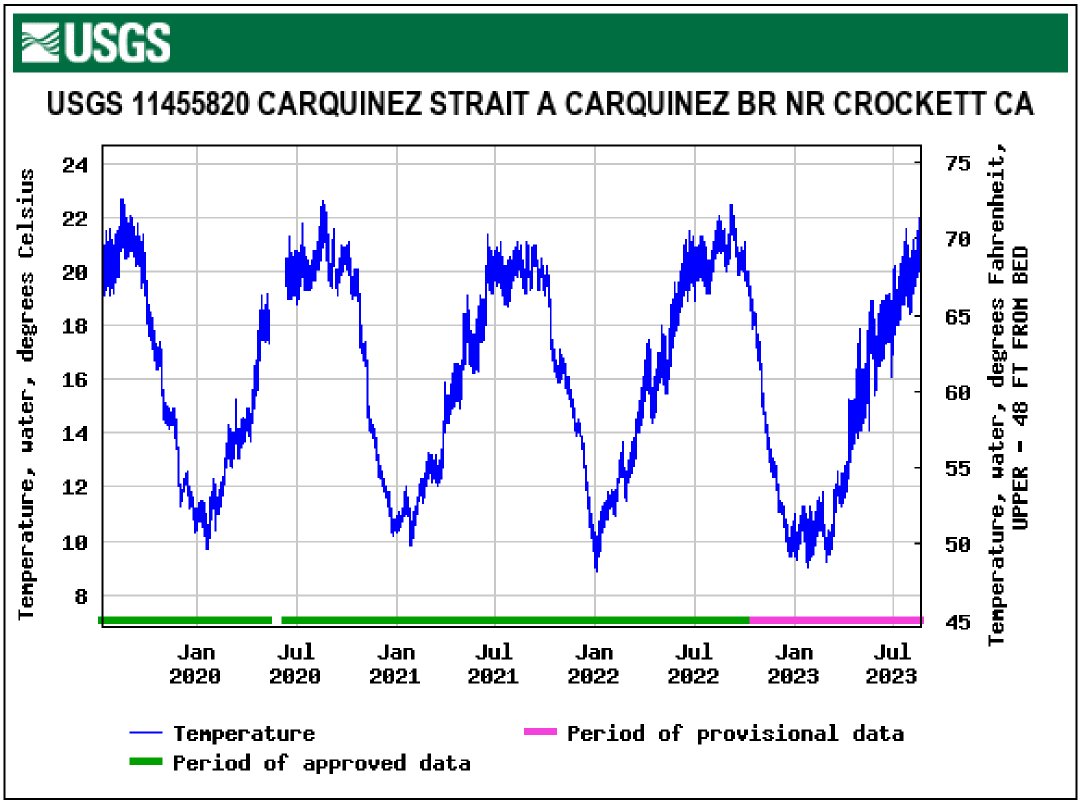

Figure E-9. Water temperature at Crockett gage between the North Bay and Suisun Bay, 2019-2023.

- *The recreational harvest of white sturgeon in California has remained relatively high in spite of a diminished population, such that monitoring of recreational capture and harvest is a primary management priority. Advances in recreational fishing techniques (e.g., use of shrimp as bait) since 1964 resulted in a rapid reduction in an initially large white sturgeon population (due to harvest prohibitions in the first half of 20th century) and continuous depletion of the few strong subsequent year classes. This is illustrated by commercial passenger fishing vessel log books data summarized by the Sturgeon Study, which shows a severe decline in catch and catch- per-unit effort (CPUE) during the first decade that shrimp were widely used as sturgeon bait (CDFW, 2016e, unpublished data, see "Notes"). This time series also shows a distinct increase in catch and CPUE in the early 1990s attributable to recruitment of the large, early-1980s year classes.*

  Comment: While the export rates (see Figure D-1) are higher than the target of 5% and an important factor in the population dynamics of the SFE white sturgeon population, it is the lack of recruitment and poor adult survival that are the dominant factors in the long-term population decline (see Figure 1).

- *Actual harvest data along with estimates of harvest rate suggest that white sturgeon populations in the SFE may be limited <u>in-part</u> by overfishing. These data are generated by the use of an age-length key, Sturgeon Fishing Report Card data, and mark-recapture data (reward tags) by the Sturgeon Study. Based on ongoing study of age at length, white sturgeon aged 13 to 15 years fall mainly within the current slot limit of 40 to 60 inches FL. Thus,* *strong mid- to late- 1990s year classes were heavily fished over the last 10 years and reduced to a population of fewer than 20,000 fish (Gingras et al. 2014). As part of the Sturgeon Study, reward tags with multiple values are applied to adult white sturgeon. Disproportionately high redemption of $100 tags relative to $20 tags and $50 tags indicates that much of the sturgeon harvest in the SFE goes unreported such that abundance estimates have likely been biased high.* (p-23)

Comment: "In-part" is the correct wording. Recovery focus should be on reducing fishery harvest, improving adult survival (in re pollution and Bay-Delta water quality), and improving age-0 recruitment. Harvest rates are likely biased to the low end. Maintaining Delta inflow and outflow in spring and summer and lowering Bay-Delta water temperatures are important short-term remedies.

- *Green sturgeon enter the Sacramento River from late winter through early summer to spawn. Stranding of green sturgeon at migration barriers in the Yolo and Sutter bypasses has only been documented in spring 2011, 2016, and 2017 (wet years). Stranding in 2011 involved at least 24 adults at stilling basins below the Yolo and Sutter Bypass Weirs (Fremont and Tisdale Weirs; Thomas et al. 2013). Entrainment and stranding of adult white sturgeon and salmonids in bypasses is fairly common when bypasses flood, but it is uncertain how bypass channels (e.g., Toe Drain, Tule Canal) affect sturgeon spawning migration during low-flow years. Gravid adult white sturgeon are collected in the Toe Drain in low-flow years when passage barriers prevent access to spawning habitat (DWR 2015). In this regard, route selection may affect inter-annual spawning success as adult sturgeon entrained in bypass channels may not reach spawning habitat within an appropriate time. Records of catch in migratory and spawning habitats are collected through CDFW creel surveys (i.e., Central Valley Angler Survey, California Recreational Fisheries Survey), Sturgeon Fishing Report Cards, and state-mandated commercial passenger fishing vessel log books. A small number of post-spawn fish are periodically collected in San Pablo and Suisun bays during late summer and early fall by the Sturgeon Study*. (p-24)

  Comment: Sturgeon migrate upstream into the bypasses in many years. In wet years, spills provide highly disproportionate rates of attraction. In dry years, low rates from agricultural and tributary inputs provide some attraction. Because the Bypasses have poor habitat and little or no upstream passage, most of the sturgeon attracted to the bypasses end up dying before the end of summer. Some may return the Bay upon being blocked, but there is little record of that behavior. The solution to this problem is providing adequate flows and water temperatures in the bypasses with enhanced upstream passage (presently planned and under construction) at the Fremont Weir at the north end of the Yolo Bypass. Such passage infrastructure improvements are needed in the Yolo Bypass, Sutter Bypass, Sacramento Bypass, and Sacramento Deep Water Shipping Channel. Until adequate passage is provided, rescues efforts of adult sturgeon are necessary. Adult sturgeon should be prevented from entering agricultural drains such as the Knights Landing Outfall, Pleasant Grove Creek Outfall, and the Butte Creek Outfall.

- *Historically, adult green sturgeon arriving to RBDD after gate closure were relegated to a warmer reach of the Sacramento River for spawning. In extreme low flows, spawning areas below RBDD may be unsuitable for green sturgeon spawning in early summer. However, temperature above RBDD was suitable for spawning in early summer even in the recent historic drought. Thus, raising the gates at RBDD expanded the accessible spawning range* *for green sturgeon and—in what may be a key element of green sturgeon life history diversity— facilitated temporal and spatial variation in spawning distribution.* (p-25)

Comment: Note that white sturgeon are "relegated" to the warmer river below the RBDD. Green sturgeon eggs and embryos are protected above the RBDD (Figure E-10) but not necessarily in the reach down to Hamilton City. White sturgeon conditions are compromised in most years for eggs and embryos (> 64ºF) in the April-May spawning period (Figure E-11). White sturgeon adults and rearing fry are compromised (> 68ºF) in June-July of most years.

- *After spawning, green sturgeon hold in-river for varying periods of time but most commonly leave the system the following fall (Benson et al. 2007; Heublein et al. 2009). Early outmigration in late spring or summer may be related to elevated flows (Benson et al. 2007; Heublein et al. 2009). For adults that over-summer in spawning or holding habitats, outmigration occurs in the late fall or (rarely) in winter after spending more than a year in freshwater (R. Chase, USACE, 2015, unpublished data, see "Notes"). Extended occupancy of those spawning and holding habitats may be related to hydrologic cues or food availability, but it is uncertain why occupancy sometimes lasts more than a year.* (p-26)

Comment: Over-summering in the Lower Sacramento River, San Joaquin River, and the Delta subjects sturgeon to stressful high water temperatures. "Hydrologic cues" are likely spring flow pulses in the rivers, which we recommend for all salmon and sturgeon.

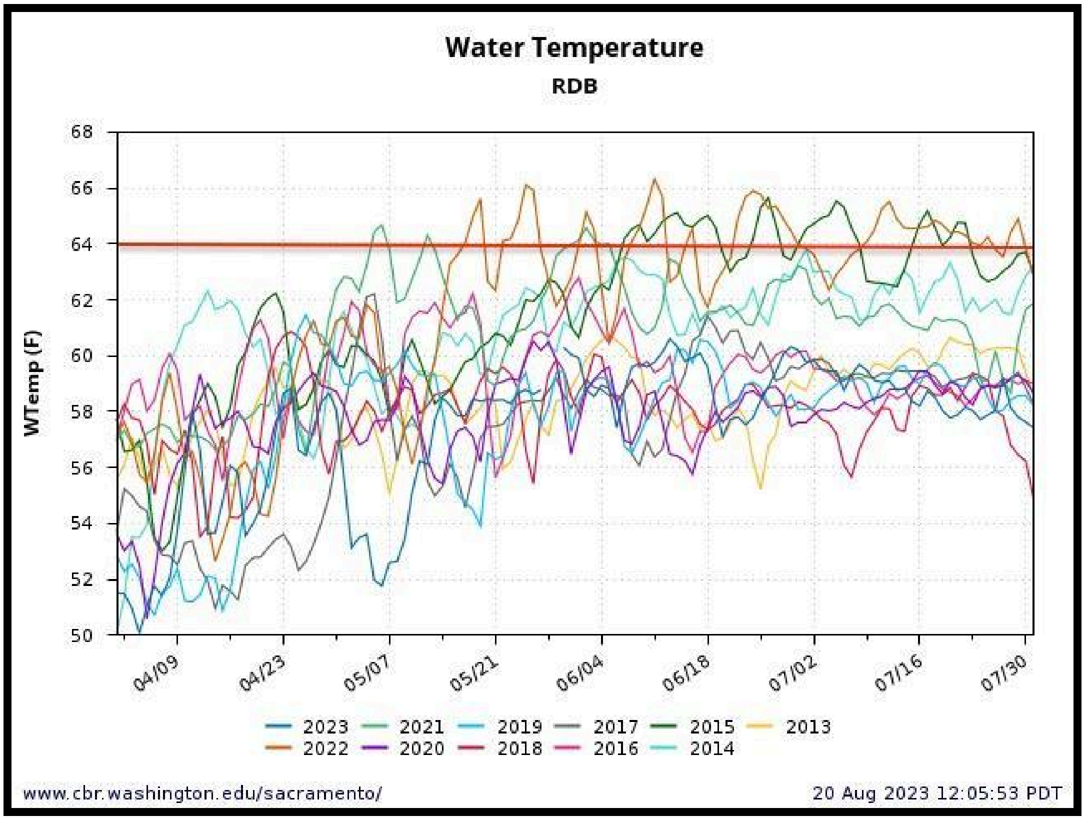

Figure E-10. Daily average water temperature in the Sacramento River in April-July, 2013-2023, at Red Bluff. The red line notes the stressful level for green sturgeon eggs and embryos.

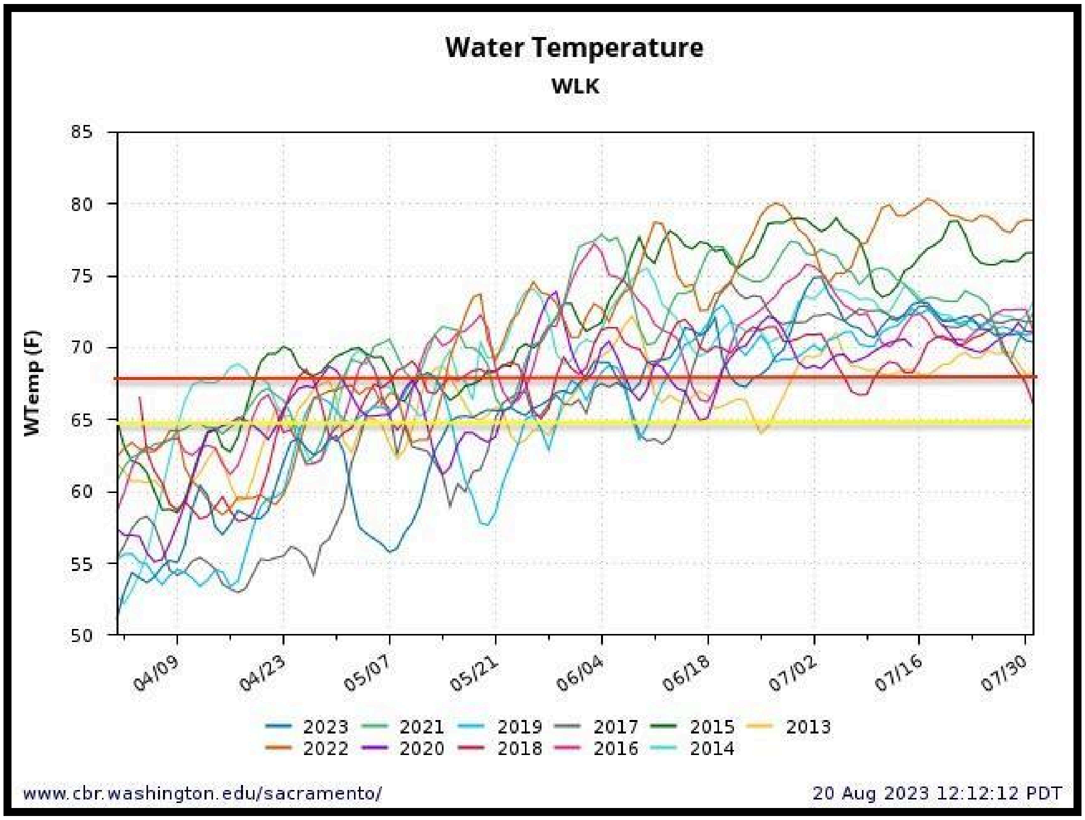

Figure E-11. Daily average water temperature in the Sacramento River in April-July 2013-2023 at Wilkins Slough. The red line denotes the stressful level for adults and fry. The yellow line denotes stressful level for eggs and embryos.

- *Migration barriers and stranding have been documented in the Yolo Bypass, Sutter Bypass, and Bear River since the mid-1980s. Those stranding events were associated with poaching and intensive legal harvest that has since been prohibited. The most recent documented events occurred in spring 2011, 2016, and 2017 (wet years) and involved stranding of adult green and white sturgeon in stilling basins below the Fremont and Tisdale Bypass Weirs. It is uncertain how bypass channels affect sturgeon spawning migration and success during low-flow years. For example, adult white sturgeon were captured in relatively high numbers from 2012 to 2014 (dry years) in a fyke trap deployed in the Yolo Bypass Toe Drain (DWR 2015). Delays in upstream sturgeon migration due to the complexity in fish passage at various bypass barriers (e.g., Lisbon and Fremont Weirs) may reduce spawning success. Stranding of adult white sturgeon in the Bear River may occur in normal or dry years. The last documented stranding event on the Bear River was in spring 2012, the first year of the recent drought. Winter and spring flow and water surface elevation on the Bear River can be highly variable even in relatively dry years. These flashy hydrograph conditions are thought to attract spawning white sturgeon to the Bear River, then subject those fish to high stranding risk.* (p-27)

Comment: See comments on page 46.

- *White sturgeon in the SFE typically return promptly to the estuary after spawning. However, adult holding through summer in freshwater spawning habitat has been documented on the Sacramento and San Joaquin rivers (Klimley et al. 2015; M. Manuel, PSMFC, 2016, personal communication unreferenced, see "Notes").* (p-28)

  Comment: Adult white sturgeon that return to the Bay after spawning are likely stressed. Bay conditions probably are important in their recovery process. Bay water temperatures above 68ºF and reduced dissolved oxygen saturation during algal blooms lead to further stress and mortality. Some adults may choose to remain in rivers to avoid the stresses of the lower rivers and Delta, and reside in cooler tailwaters below the rim dams. Because the SFE becomes too warm in summer, movement to the local ocean may be initiated to relieve stress. Note that this may be one reason why the green sturgeon may migrate to reside in summer in northern estuaries (e.g., Klamath, Rogue, Columbia rivers).

F. Green Sturgeon in California

a) Green Sturgeon in California: Hidden Lives Revealed From Long-Term Tracking

- *First, we showed that during spring months (Fig. 3, left), there is a single pulse of upriver migrants towards spawning grounds in the upper Sacramento River, consistent with other observations (Steel et al. 2018). The upriver migration occurs during March and April but fluctuates within that time range across years.*

  Comment:

b) White sturgeon is an ancient survivor facing extinction in California. Posted on November 6, 2022 (Schreier et al 2022).

This article is about

c) Individual habitat use and behavior of acoustically-tagged juvenile green sturgeon in the Sacramento-San Joaquin Delta (Thomas et al. 2019)

The study was conducted on the behavior of six acoustically-tagged yearling green sturgeon released into the lower San Joaquin River channel in the central Delta in 2008 and 2010. The study indicated the yearling sturgeon remained for the most part near the bottom in relatively deep water. Of note, all six fish were released and tracked in water at or below 70°F.

- *During the spring (April through June) reproductively mature Green Sturgeon arrive at the upper reaches of the Sacramento River to spawn (Heublein et al. 2009). Larval Green Sturgeon begin emerging from the gravel in early April, with peak abundance occurring during May and June (Poytress et al. 2015).*
- *There is uncertainty around when young of year (YOY) Green Sturgeon leave the natal spawning ground and begin emigration to the putative rearing grounds of the Sacramento-San Joaquin Delta (SSJ Delta). It is likely that downstream emigration from the spawning grounds begins in early to late fall when water temperatures fall below the optimum necessary to promote grow (Mayfield and Cech 2004).*

  Comment: It seems likely that the occurrence of larval and early juvenile (young of the year) green sturgeon peaking in abundance from late May to mid July at Red Bluff (see Figure Fa-1) would remain in the river near Red Bluff through the summer as the lower river is too warm for successful rearing. It is more likely that some age-0 green sturgeon remain in the upper river until late fall to emigrate as sub-yearlings (note the small number of larger juveniles in Figure Fa-1). The "normal" pattern is likely movement to the Bay-Delta with spring-snowmelt flows. Those green sturgeon young that attempt the "normal" pattern would not likely survive the lower river and Delta during late spring and summer of all but the wettest years due to stressful or lethal water temperature conditions (70-75°F). Our proposed spring pulse flow and <68°F water temperature criteria in the lower Sacramento River and <72°F for the north Delta are prescribed to benefit green sturgeon survival. To further green sturgeon reproductive success, we recommend all captured green sturgeon at the array of traps at Red Bluff be transferred to a conservation hatchery and later released into the Bay.

- *Juveniles may spend the next two to three years rearing in the complex network of waterways known as the SSJ Delta and the San Francisco estuary (Moyle 2002).*

Comment: This may have been the historical pattern, but today water temperatures are too high to sustain juvenile green sturgeon through the summer in most years (see Figure Fa-2). While green sturgeon are likely found in the interior Delta in summer like white sturgeon (see Figure E-3), they were probably drawn toward the interior Delta by the south Delta export pumps. For this reason, we recommend that all salvaged sturgeon be transported to a sturgeon conservation hatchery for later release to the Bay.

- *Information from monitoring studies of other species does provide a coarse picture of early life movement patterns of juvenile Green Sturgeon. In the upper river, captures of juvenile Green Sturgeon peak between May and June (Poytress et al. 2015). It is believed that young of the year begin their downriver migration to the SSJ Delta at the onset of winter, as temperatures in the upper watershed drop below the thermal optima (15–19 °C) for growth at this life stage (Mayfield and Cech 2004; Poletto et al. 2018; Hamda et al. 2019). Typically, the lower reaches of the Sacramento River and SSJ Delta are warmer in the winter months compared to upstream habitats and may result in accelerated growth. Juveniles undergo physiological changes similar to salmonids for osmoregulation (pseudo-smoltification) by age-2 (Allen and Cech 2007; Poletto et al. 2013).*

  Comment: The observation of so many larval green sturgeon captured at Red Bluff and the knowledge that green sturgeon also spawn below Red Bluff indicates a risk to green sturgeon larvae production that rear in the lower Sacramento River under stressful/lethal condition in summer (the state water quality standard of < 20ºC/68ºF is no longer being met, see Figure Fa-3).

- *Five larval sturgeon, two in 2008 and three in 2010, ranging in size from 24 to 28 mm were captured using rotary screw traps operated by U.S. Fish and Wildlife Service (USFWS) adjacent to the Red Bluff Diversion Dam (RBDD) [RKM 378, measured from the Golden Gate Bridge] in Red Bluff, California (Poytress et al. 2009; Poytress et al. 2010). One juvenile Green Sturgeon (GS1) was captured at the south SSJ Delta pumping facilities located near Tracy, California in July, 2008. All individuals originating from USFWS were transferred to the U.S. Bureau of Reclamation wet laboratory adjacent to RBDD. Larval sturgeon were reared in a 1.2 m circular tank filled to a depth of 0.6 m.*

  Comment: Note the ability to capture and rear juvenile sturgeon in a controlled facility. We recommend using such facilities as conservation hatcheries.

- *Tank water at the RBDD facilities was flow through, coming directly from the Sacramento River. Therefore, all temperatures were equivalent to the source and represented the natural thermal regime. When individuals held at the RBDD site reached a size of approximately 50 mm they were transported to the Center for Aquatic Biology and Aquaculture (CABA) in Davis, California. While at CABA, water temperatures were kept between 15 and 17 °C, near the thermal optimum for growth (Mayfield and Cech 2004; Van Eenennaam et al. 2005; Poletto et al. 2018).*

  Comment: The "natural termal regime" at Red Bluff is much different than the thermal regime the larval sturgeon would encounter in the 200 miles of the lower river and the

Delta. Note the optimal water temperature for sturgeon is below 65ºF/18ºC. We recommend a maximum water temperature in the lower Sacramento River of 65ºF in April and May.

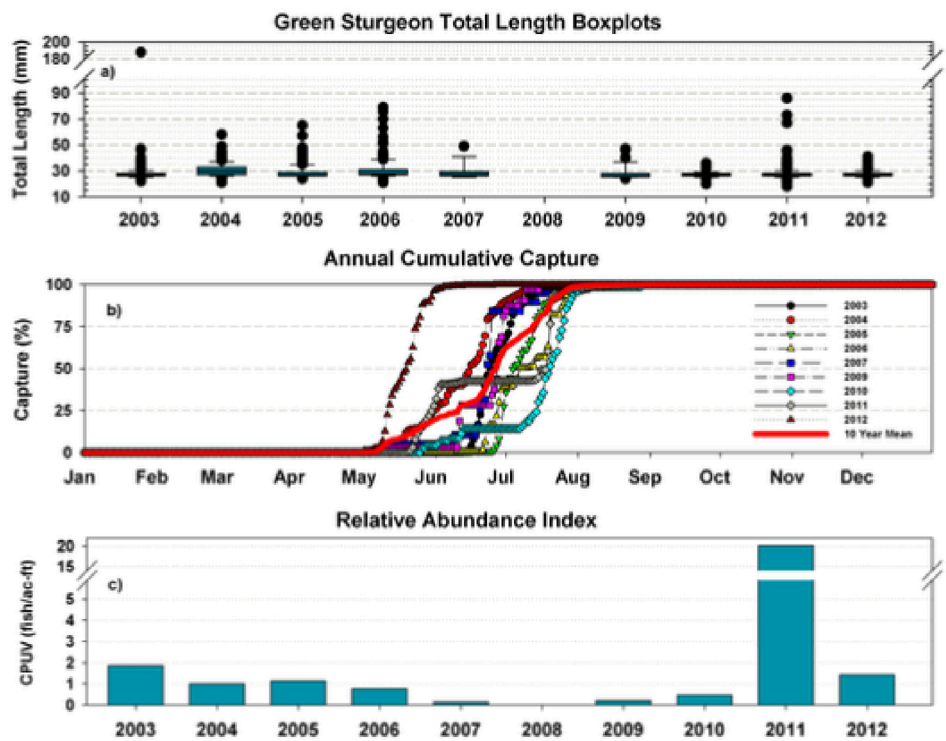

Figure 21. Green sturgeon a) annual total length capture boxplots, b) annual cumulative capture trends with 10-year mean trend line, and c) relative abundance indices.   All fish captured by rotary trap at RBDD (RM 243) on the Upper Sacramento River, CA between 2003 and 2012. Data from 2002 excluded from analysis due to limited effort and USBR Crown Flow study resulting in incomparable sampling regimes and results.

Figure Fa-1. Relative abundance index, timing, and size distribution of age-0 green sturgeon captured in Red Bluff screw traps by the US Fish and Wildlife Service. Note that most age-0 green sturgeon are fry captured at a mean size of 30-mm as they move downstream past Red Bluff from late May to mid-July.

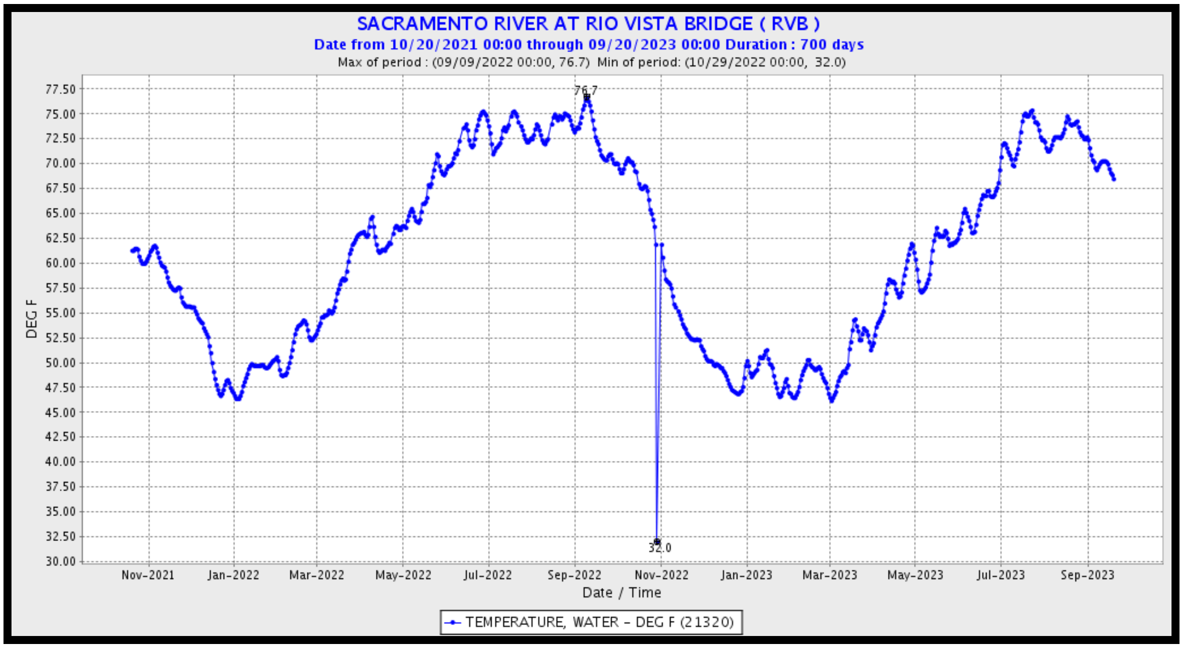

Figure Fa-2.

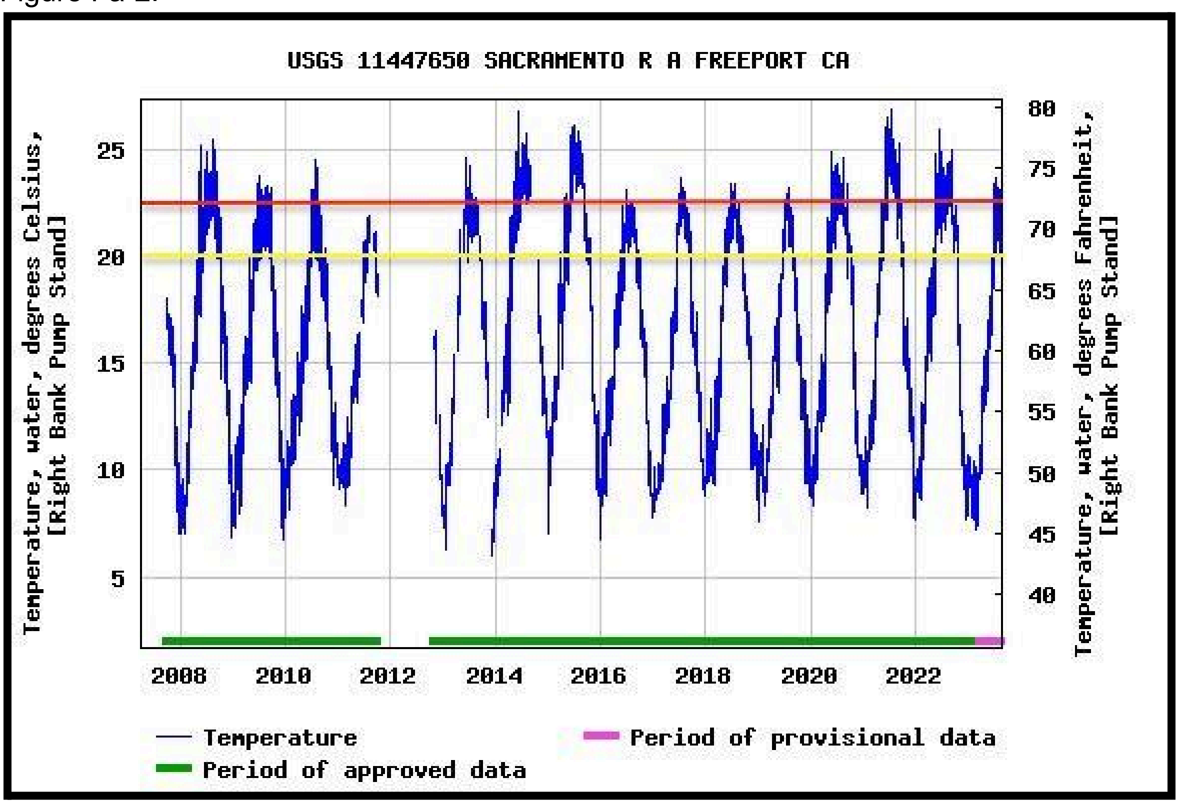

Figure Fa-3. Water temperature in lower Sacramento River near entrance to the Delta at Freeport in water years 2007-2023. Yellow line is water quality standard for the lower Sacramento River and stressful level for sturgeon. Red Line is beginning of high stress and lethal conditions for sturgeon. It is our recommended maximum allowed water temperatures for the Delta. The five years when temperatures exceeded 75ºF were critical drought years 08, 14, 15, 21, and 22 (which occur in about 33% of years in recent decades).

G. Recovery Plan for the sDPS of North American Green Sturgeon (NMFS 2018)[2]

Threat-Based Recovery Criteria (p2)

1. *Access to spawning habitat is improved through barrier removal or modification in the Sacramento, Feather, and/or Yuba rivers such that successful spawning occurs annually in at least two rivers. Successful spawning will be determined by the annual presence of larvae for at least 20 years.*

   Comment: The Sacramento Valley flood control system has many flood control and water supply weirs and diversion dams that may block green sturgeon passage. A threat matrix should be developed for each potential site and an overall assessment should be completed with appropriate actions to lower risks identified. An interim rescue and rehabilitation program is necessary at problem sites prior to completing fixes. Rescued sturgeon should be transferred to conservation hatchery for rehabilitation before releasing to the Bay.

2. *Volitional passage is provided for adult green sturgeon through the Yolo and Sutter bypasses.*

   Comment: This should apply to the four major Corps flood bypass weirs as well as all other weirs and overflows (Angel Slough overflow), as well as attraction-delays at various basin outflows. A notch providing passage has been constructed at the Fremont Weir. A notch is planned at the Tisdale Weir. Until the notches are constructed and effectively operated, adult sturgeon rescues will be necessary.

3. *Water temperature and flows are provided in spawning habitat such that juvenile recruitment is documented annually. Recruitment is determined by the annual presence of age-0 juveniles in the lower Sacramento River or San Francisco Bay Delta Estuary. Flow and temperature guidelines have been derived from analysis of inter-annual spawning and recruitment success and are informing this criterion.*

   Comment: Middle and lower river and Delta water temperature in spring and early summer are lethal to larval and early juvenile sturgeon. Summer water temperatures are too high for juvenile sturgeon (age-0 to age-4) in the Delta. We have recommended a maximum water temperature of 72ºF in summer in the north and central portions of the primary Delta.

4. *Adult contaminant levels are below levels that are identified as limiting population maintenance and growth.*

   Comment: Excessive dissolved and particulate organic carbon (mainly from plankton blooms) in association with warm water lead to low dissolved oxygen levels in summer

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[2] NOAA_18695_DS1.pdf

in the Bay (less than 50% saturation and 5 mg/l. The water quality standard requires >5mg/l dissolved oxygen in Bay waters.

5. *Operation guidelines and/or fish screens are applied to water diversions in mainstem Sacramento, Feather, and Yuba rivers and San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment.*

   Comment: Entrainment of larval sturgeon and salvage of early juveniles occurs in spring and summer at south Delta export pumps. We recommend screening of Delta Cross Channel and Georgianna Slough to limit entrainment of larval and juvenile sturgeon into the interior Delta.

6. *Take of adults and subadults through poaching and state, federal and tribal fisheries is minimal and does not limit population persistence and growth.*

   Comment: Because the extent of take from legal and illegal fisheries is unknown, a more aggressive evaluation and enforcement program is needed to evaluate the effects and possible remediation measures.

- *Larval green sturgeon are suspected to remain near spawning habitats. Larval white sturgeon are periodically collected during high outflows in the San Francisco Bay Delta Estuary, well downstream of documented white sturgeon spawning habitat. Based on this and in the absence of complete larval green sturgeon survey data, we estimate that larval distribution could extend 100 km or more downstream from spawning habitats on the Sacramento and Feather rivers in high flow years. This estimated downstream distribution corresponds with the Colusa area on the Sacramento River (rkm 252) and the confluence of the Sacramento and Feather rivers near Verona (rkm 129) for larvae originating in the Sacramento and Feather Rivers, respectively.* (p7)

  Comment: The upper spawning reach of the green sturgeon in dry and most wet years gets little natural flow in spring and summer as precipitation is held in Shasta Reservoir. Natural flow pulses from tributaries (e.g., Battle Creek) in wet years help transport larvae to the Bay, which is the main reason better brood years occur in wet years. Otherwise larvae and early juveniles succumb to warm river and Delta in late spring and summer of drier years.

- *It is unknown how long juveniles remain in upriver rearing habitats after metamorphosis. Based on length distribution data from salvage and recent upstream surveys, juveniles typically enter the Delta as sub-yearlings or yearlings to rear prior to ocean entry. The Sacramento River is an important migratory corridor for larval and juvenile sturgeon during their downstream migration to the San Francisco Bay Delta Estuary. The San Francisco Bay Delta Estuary provides year-round rearing habitat for juveniles, as well as foraging habitat for non-spawning adults and subadults in the summer months (NMFS 2009c).* (p7)

  Comment: In some critical drought years like 2022 sturgeon fry have limited transport flows. In other dry years like 2021 there are greater flows supporting migrations but only in the valley feeding water diversions. In wet years like 2023 high transport flows end in late spring and subsequently are too low. In these recent example years, below the major water diversions flows are low (Figure G-1) and water temperatures are high (Figure G-2), therefore putting the young sturgeon at risk after being stimulated to emigrate. Lower than normal flows (5000 cfs compared to 7000 cfs) in early July 2023 led to water temperatures reaching 75ºF.

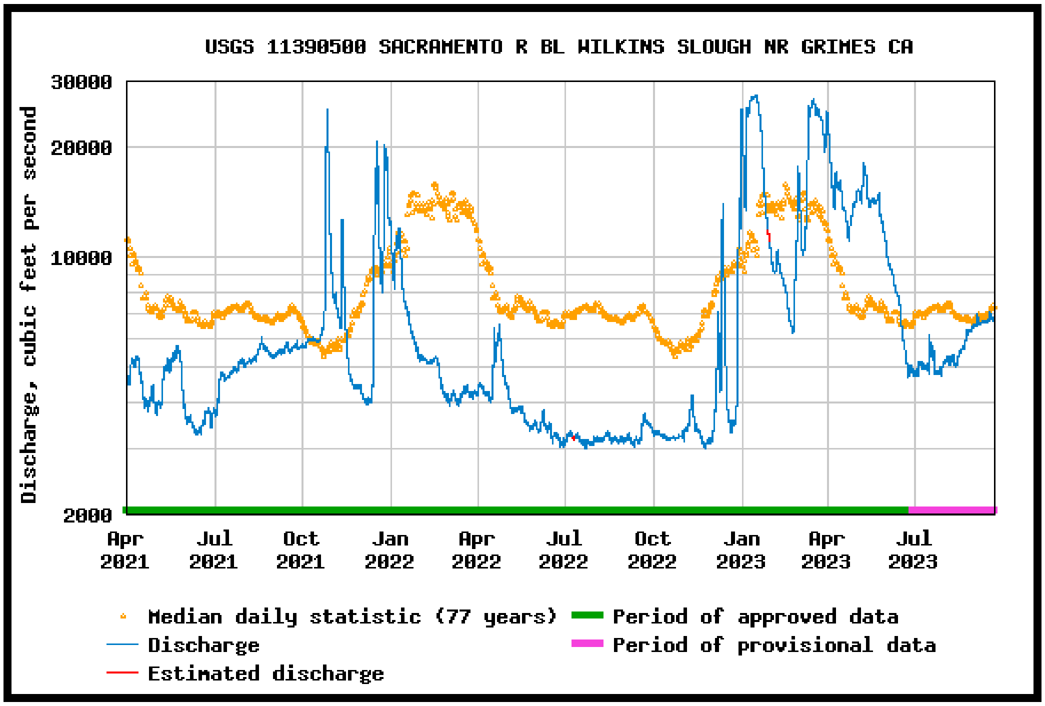

Figure G-1. Sacramento River stream flow at Wilkins Slough (rm 120) below the last major Sacramento River water diversion above the Feather River.

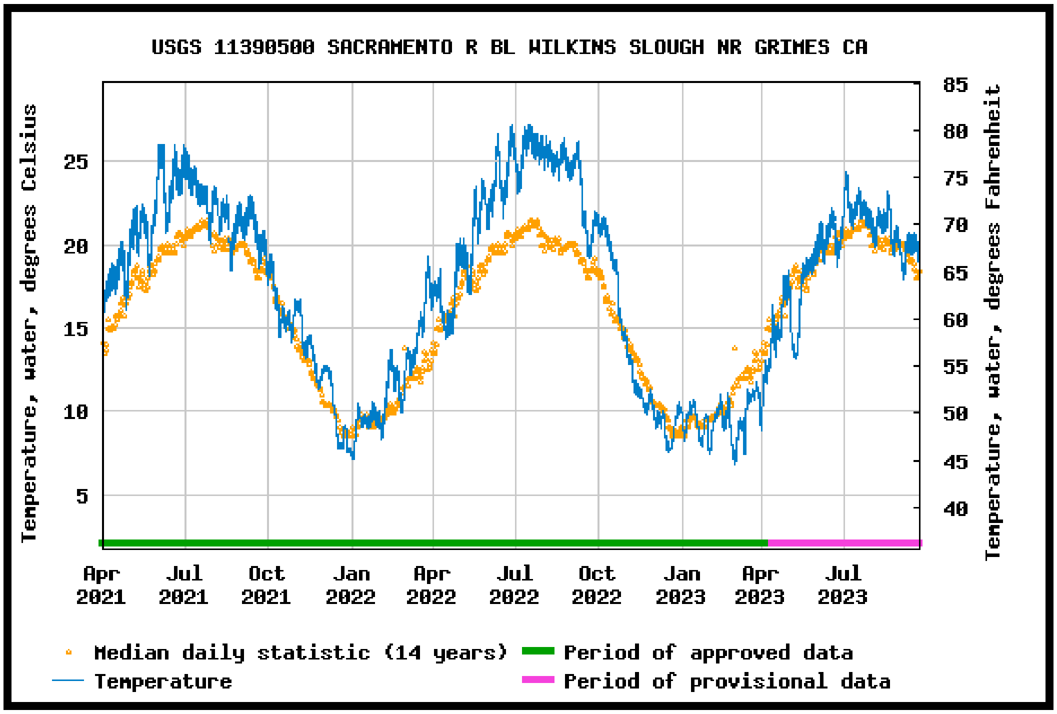

Figure G-2. Water temperature at Wilkins Slough (rm 120) below the last major Sacramento River water diversion above the Feather River.

- *Water flow is an important cue in spawning migration for both nDPS and sDPS green sturgeon, with outmigration related to elevated flows (Benson et al. 2007; Erickson and Webb 2007; Heublein et al. 2009; Poytress et al. 2011, 2012; University of California at Davis, unpublished data). In white sturgeon, spawning has been documented to occur after elevated flows (Schaffter 1997; Jackson et al. 2016), suggesting a connection between flow and spawning.* (p8)

- *Southern DPS spawning primarily occurs in cool sections of the upper mainstem Sacramento River in deep pools (averaging 8-9m in depth; Wyman et al. 2018) containing small to medium sized sand, gravel, cobble, or boulder substrate (Klimley et al. 2015a; Poytress et al. 2015; Wyman et al. 2018). Post-spawn fish may hold for several months in the Sacramento River and out-migrate in the fall or winter or move out of the river quickly during the spring and summer months, with the holding behavior most commonly observed (Heublein et al. 2009; Mora 2016). Post-spawn outmigration through the San Francisco Bay Delta Estuary is also variable, with some individuals migrating to the Pacific Ocean rather quickly (2-10 days) and others remaining in the estuary for a number of months after leaving upstream holding habitats (Heublein et al. 2009).* (p8)

- *Van Eenennaam et al. (2005) found that the hatching rate for green sturgeon eggs was slightly reduced when incubation temperatures were less than 11°C. They also found that the upper lethal temperature for developing embryos was 22-23°C, with sub-lethal effects occurring at 17.5 to 22.2°C (Van Eenennaam et al. 2005). (p12)*

  Comment: We recommend lower Sacramento River water temperatures above Freeport not exceed 18°C/65°F in spring (March-May) and 20°C/68°F in summer. Summer water temperature standards are often often exceeded in summer (Figure G-3). Streamflows around 7,000 cfs are need to maintain water temperatures at or below 20°C/68°F (Figure G-4).

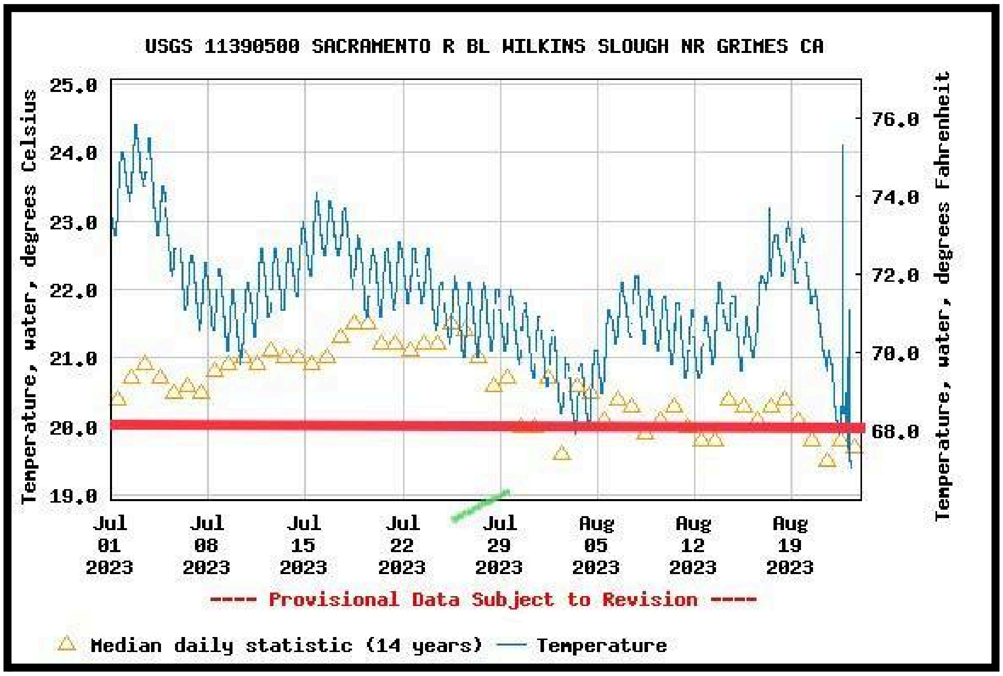

Figure G-3.

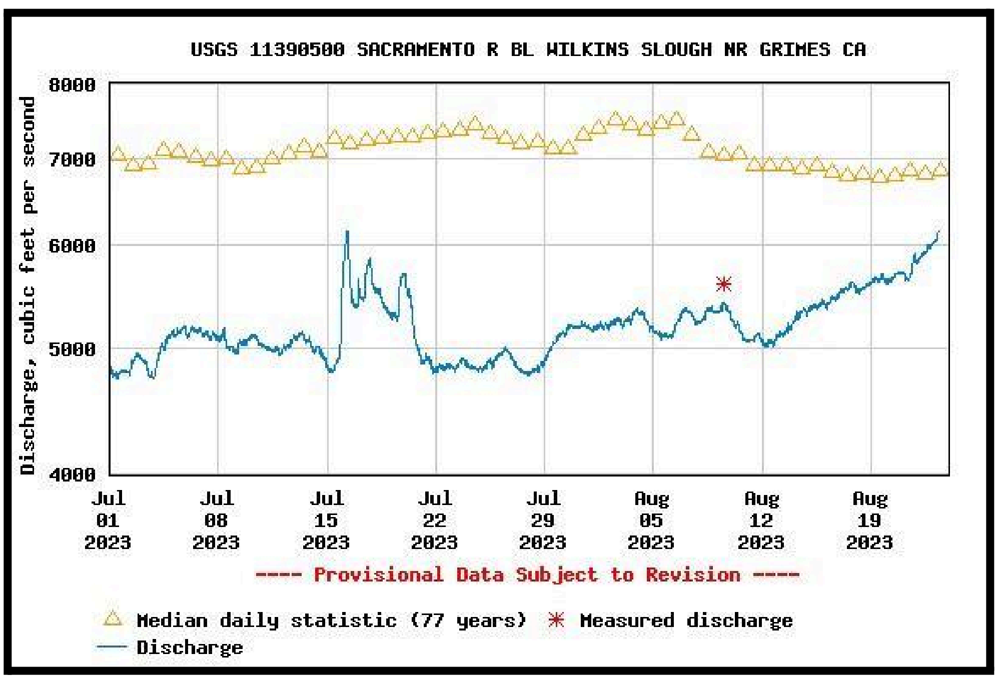

Figure G-4.

- *Larval abundance and distribution may be influenced by spring and summer outflow and recruitment may be highest in wet years, making water flow an important habitat parameter* *(reviewed in Heublein et al. 2017a). California Department of Fish and Game (CDFG 1992) and USFWS (1995) found a positive correlation between mean daily freshwater outflow (April to July) and white sturgeon year class strength in the San Francisco Bay Delta Estuary. These studies involved the more abundant white sturgeon, which has life history requirements similar to those of green sturgeon. This correlation is consistent with relationships found for other anadromous fish in the estuary and may be due to the fact that flows transport larvae to areas with greater food availability, disperse larvae over a wider area, or enhance nutrient availability.* (p12)

Comment: Larval green sturgeon must get from the spawning area near Red Bluff 200 miles to the Bay to survive the high water temperatures of late spring and summer. Larval white sturgeon must move from 100-150 miles from their spawning area in the lower river to the Bay. By summer the lower river has lethal water temperatures for the young sturgeon because of low flows not just in dry years but also in recent wet years such as 2023 (Figures G4 and G-5). We recommend maintaining the 68ºF water quality standard through the summer to protect the larval sturgeon, which requires 6000-8000 cfs flow in the lower river depending on ambient air temperatures. Historically, these flows and water temperatures were maintained in most years not just wet years.

- *Temperature is also a factor in larval and juvenile development and has been the subject of several laboratory studies involving nDPS green sturgeon. Linares-Casenave et al. (2013) found that the survival of green sturgeon larvae to yolk-sac depletion was optimal at 18-20°C, sub-optimal at 22-26°C, and lethal at 28°C in a laboratory setting. Cech et al. (2002) found that optimal temperature for larval growth was 15°C, with temperatures less than 11°C or greater than 19°C reducing growth rates. Werner et al. (2007) also suggested that temperature should remain below 20°C for optimal larval development. Mayfield and Cech (2004) found that age-0 and age-1 sDPS green sturgeon tested under laboratory conditions had optimal bioenergetic performance (i.e., growth, food conversion, swimming ability) between 15-16°C, with an upper limit of 19°C (Mayfield and Cech 2004; Allen et al. 2006).* (p12)

  Comment: The water quality standard (68ºF/20°C) for the lower Sacramento River in the Basin Plan and the water projects state water right permits was established based on the best available science. For the most part the standard was accepted and met, even over the past two decades (Figure G-4).

- *As indicated above, it is unknown how long juveniles remain in upriver rearing habitats after metamorphosis, but they likely spend the first several months in freshwater environments. In the laboratory, juvenile nDPS were highly tolerant of changes in salinity during the first 6 months (Allen et al. 2011) and the ability to transition to seawater occurred at 1.5 years of age (Allen and Cech 2007). Results from Klimley et al. (2015b) suggest that some individuals in the sDPS may enter the ocean and transition to the subadult life stage in their first year, but typical length of fish encountered in the ocean (>600-mm TL) suggests ocean entry occurs at a later age.* (p13)

  Comment: It is generally assumed based on various monitoring surveys that the green sturgeon (and white sturgeon) nursery area is the Bay (including the east, north, and south Bays). Age-0 production of green sturgeon may also depend on the upper river near Redding where over-summering of green sturgeon juveniles has been observed. Green sturgeon recruitment likely depends on the upper Sacramento River and Bay conditions during the first two years of their life cycle. For the majority of the white sturgeon, the Bay appears to be their most important nursery and adult habitat with spring-through-fall conditions being the most important growth and survival period, and over-summering in the Bay and spring spawning in the rivers being critical survival periods.

- *In the estuarine environment, green sturgeon are exposed to varying water temperatures, salinities, and dissolved oxygen (DO) concentrations. For example, green sturgeon in coastal estuaries have been detected in water temperatures ranging from 11.9-21.9°C, salinities from 8.8-32.1 parts per thousand, and DO from 6.54 to 8.98 milligrams of oxygen per liter (Kelly et al. 2007; Moser and Lindley 2007).* (p13)

  Comment: Because these conditions are often exceeded in at least portions of San Francisco Bay, it may be one of the reasons green sturgeon migrate north along the coast and over-summer in more northern estuaries. White sturgeon may do the same for these same reasons but to a lessor degree.

- *A recent analysis indicates that current seasonal and overall flow patterns in the Sacramento River substantially differ from unimpaired flows (State Water Resources Control Board 2016). Peak fall and winter flows are reduced in both wet and critically dry water year types at Bend Bridge, with the recession limb of the spring snowmelt truncated or absent, and base flows in summer augmented (Figure 8a). Water flow into the Delta has also been significantly altered, with peaks in flow in winter and spring greatly reduced by upstream storage and replaced by increased summer and early fall flows. Water reaching the Delta is also pumped out for various uses, impacting available water, habitat, and salinity. Delta outflows have been significantly reduced overall as a result (Figure 8b). These changes could negatively impact the sDPS through changes to spawning and rearing habitats and migration cues.* (p14)

  Comment: These changes or impacts of the water projects have limited the capacity of the Central Valley and Bay-Delta to produce green and white sturgeon.

- *The sDPS of green sturgeon was listed as threatened because of the following factors (71 FR 17757, April 7, 2006): (1) the Sacramento River contains the only known sDPS spawning population; (2) there has been a substantial loss of spawning habitat in the upper Sacramento and Feather Rivers; (3) the Sacramento River and Delta System face mounting threats to habitat quality and quantity; and (4) fishery-independent data indicated a decrease in observed numbers of juvenile green sturgeon collected. While some threats have been addressed (see NMFS 2015 for full description), many remain and are discussed below. The listing Biological Review Team (BRT) considered additional threats (e.g., entrainment, contaminants, fisheries bycatch, poaching, marine and estuarine energy projects, non-native species); however, due to a high level of uncertainty, they were characterized as "potential" risk factors for which future research was recommended.* (p14)

  Comment: Our recommendations include addressing the primary factors but also entrainment, fishery bycatch, poaching, and controls on non-native predator/competitors.

- <u>*Altered Water Temperature*</u>

- *The threat posed by altered water temperatures due to impoundments was ranked High in the SRB for eggs and juveniles, with medium data sufficiency. Impoundments alter flow regimes, which in turn affect the water temperature of the river downstream of the impoundment. If water released from the impoundments results in water temperatures that are not within the optimal thermal window for development, survival and growth will be limited.* (p28)
- *In the Feather River, spawning has only been documented at the Thermalito Afterbay Outlet and Fish Barrier Dam (Figure 3). Late spring and summer water temperature in the lower Feather River can exceed suitable ranges for normal egg and larval development (NMFS 2016). Green sturgeon spawned in 2011 and 2017 in the Feather River at the Thermalito Afterbay Outlet and Fish Barrier Dam, respectively. Water temperature was substantially cooler than average in both years, likely due to the above average flow that occurred in spring.* (p28)
- *Temperatures in the Yuba River should be evaluated as other sDPS restoration efforts described within this plan are undertaken. A 2010 report suggested that late summer and early fall water temperatures were too warm to support green sturgeon reproduction (Lower Yuba River Accord River Management Team Planning Group 2010). More recent analysis suggests that temperatures fall within optimal ranges (YCWA 2017). If upstream sturgeon passage is restored within the Yuba River, temperature suitability should be reevaluated using information on sDPS of North American Green Sturgeon optimal temperature windows potentially made available through future monitoring in the Sacramento and Feather rivers.* (p28)

  Comment: Spring runoff reductions from reservoir inflow storage capture in the Central Valley causes excessive water temperatures in the lower Sacramento River in the Apr-May spawning and egg/embryo development period. We have given this factor a Number 1 rating (see Figure 7). We recommend 60°F (16°C) in the green sturgeon spawning areas of the upper Sacramento and lower tributaries in the April-May period. For example, in the lower Yuba River near Marysville, a known and potential spawning reach of green sturgeon, the 60°F target is often not met in dry years because flows are too low (Figures G-5 and G-6). Too meet our recommended target, lower Yuba River flows should be maintained at a minimum of 800 cfs (see Figures G-7 and G-8) through May. Another example is the lower Feather River (above the Afterbay outlet) where the target is not met in some dry years (Figures G-9 and G-10). To meet the target, lower Feather River flows in the low-flow section near the hatchery should be maintained near 1000 cfs.

- *The threat posed by altered water temperatures due to climate change was ranked as High or Very High in the SRB (all life stages except eggs), CBE, and NM, with low data sufficiency. Future changes in weather patterns, ocean currents, and marine and freshwater temperatures are potential sources of uncertainty for green sturgeon throughout the west coast of North America. In the SRB, climate change models predict increased air temperatures in the Central Valley and surrounding mountains (Ficklin et al. 2012), altered precipitation patterns with a higher frequency of dry years, reduced spring snowpack, and reduced spring flows (Knowles and Cayan 2002; CH2M HILL 2014). Water temperatures in the SRB could also increase (CH2M HILL 2014). <u>A warming climate with continued changes in precipitation patterns may influence reservoir operations and thus influence water temperature and flow that sDPS experience in the Sacramento, Feather, and Yuba rivers</u>.* (p31)

Comment: The higher frequency of dry years, reduced snowpacks, and reduced spring flows are already occurring. The big concern is the spring water temperatures in the Sacramento River in dry years that have already and will increasingly limit sturgeon reproductive success. Our recommended spring flows and water temperatures are necessary to maintain existing reproduction of green and while sturgeon and will lead to recovery of the two populations.

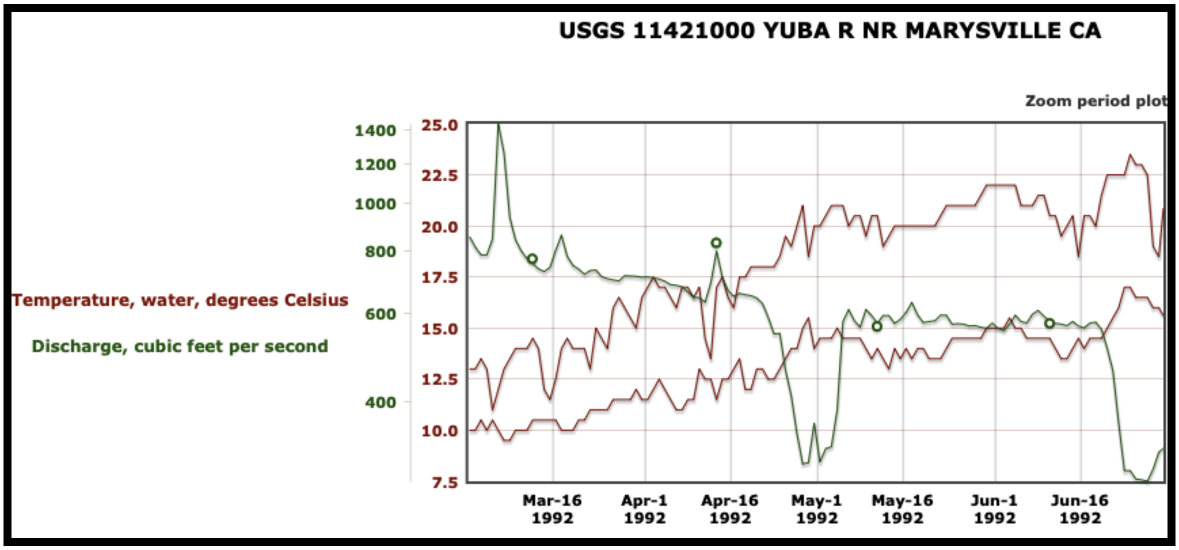

Figure G-5. Minimum and maximum daily water temperatures in the Yuba River at the Marysville gage Mar-Jun in dry year 1992.

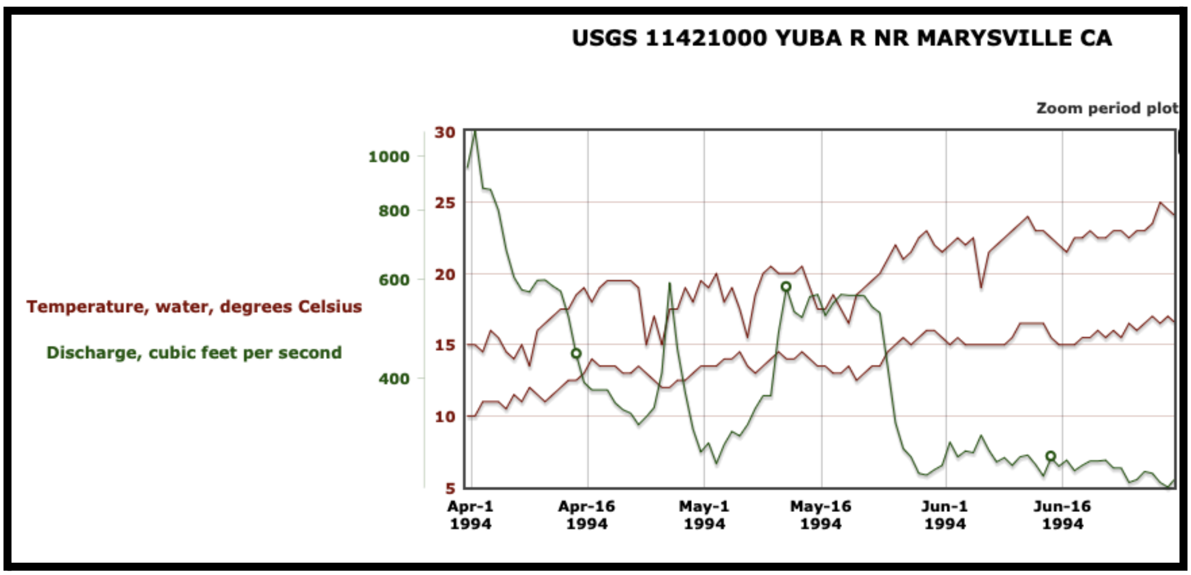

Figure G-6. Minimum and maximum daily water temperatures in the Yuba River at the Marysville gage Mar-Jun in dry year 1994.

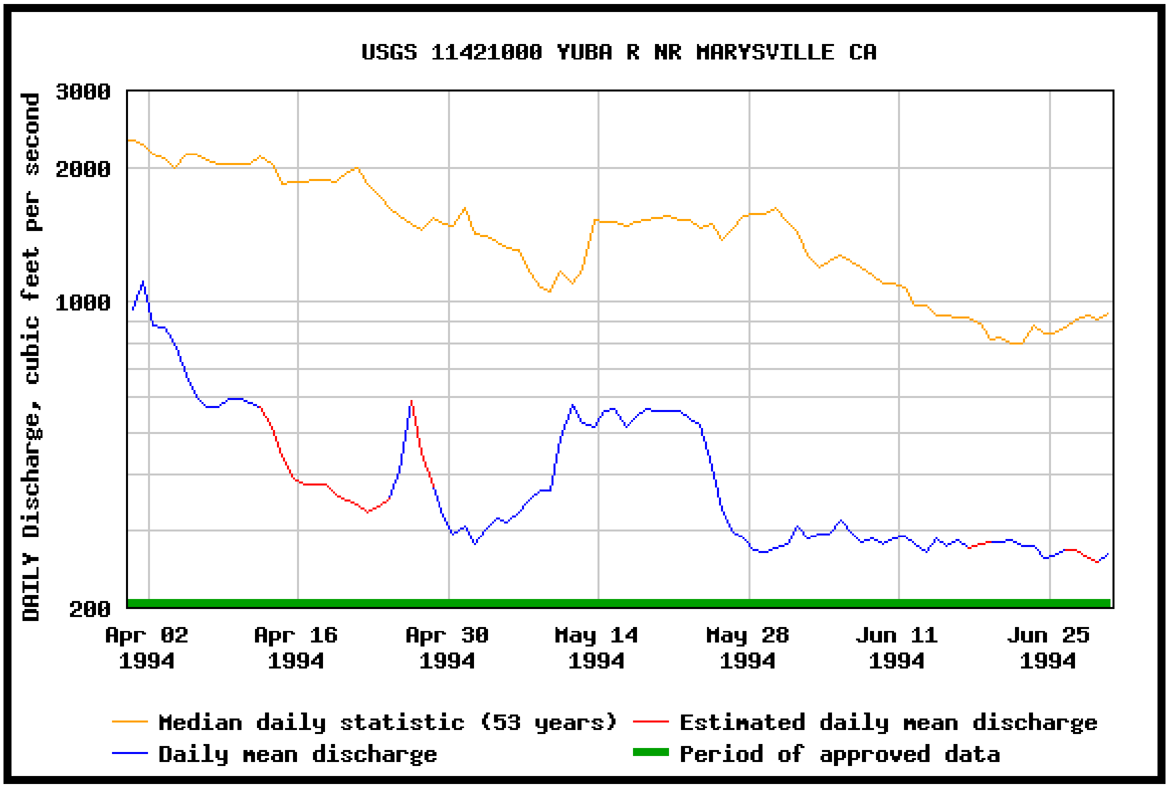

Figure G-7. Mean daily streamflow in lower Yuba River at the Marysville gage Apr-Jun in dry year 1994.

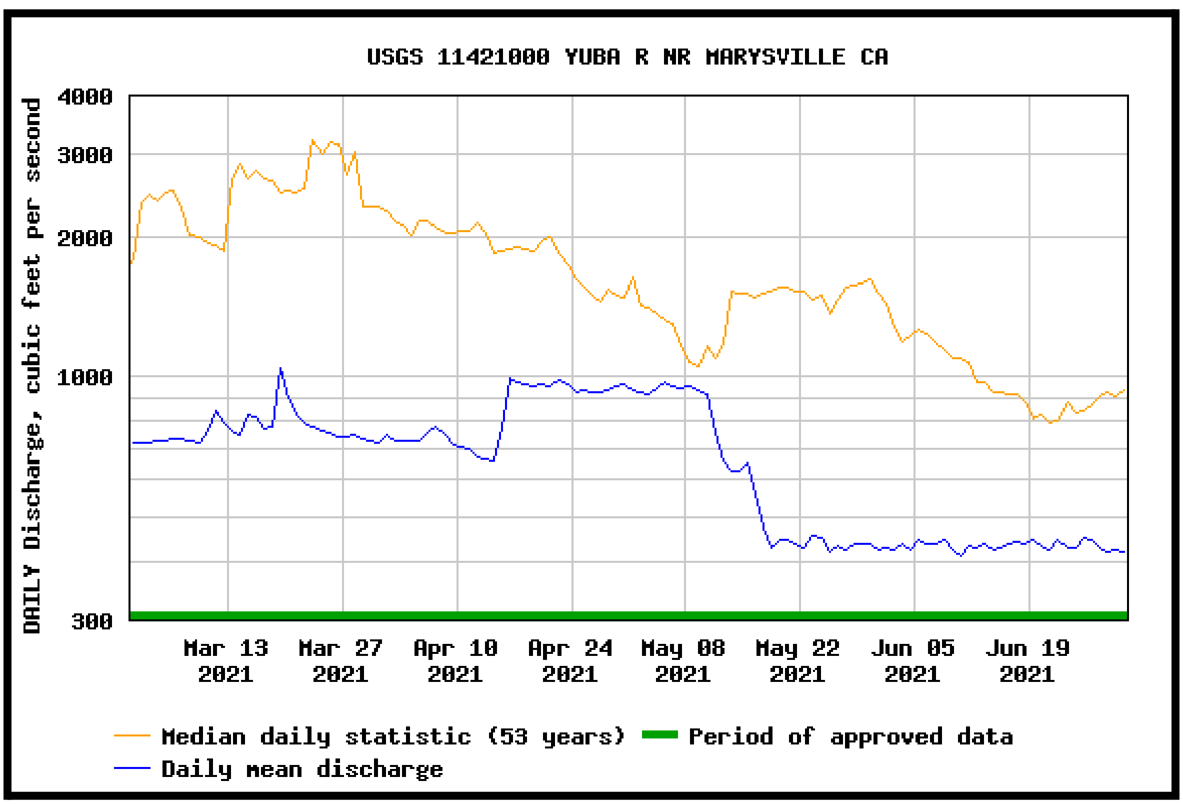

Figure G-8. Mean daily streamflow in lower Yuba River at the Marysville gage Apr-Jun in dry year 2021.

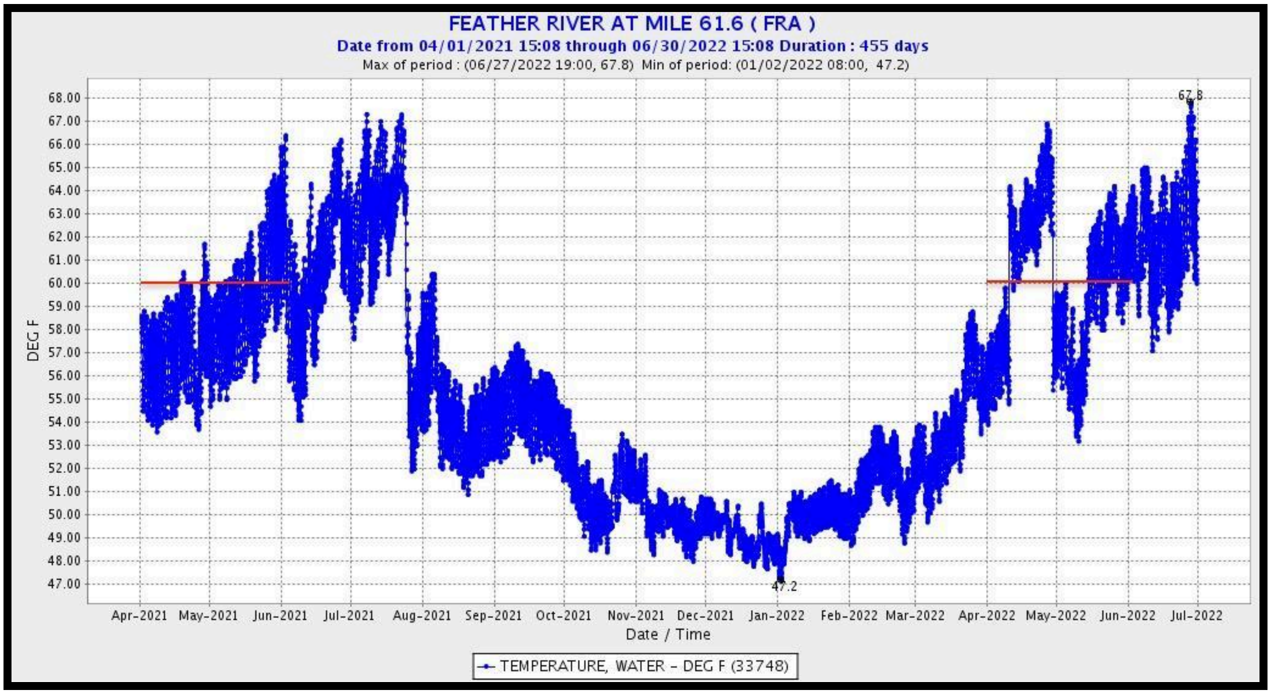

Figure G-9. Hourly water temperatures in the lower Feather River upstream of Afterbay inlet in the low-flow section Apr 2021 to July 2022 (dry years). Note red lines where water temperatures exceeded recommended 60°F in Apr-May period.

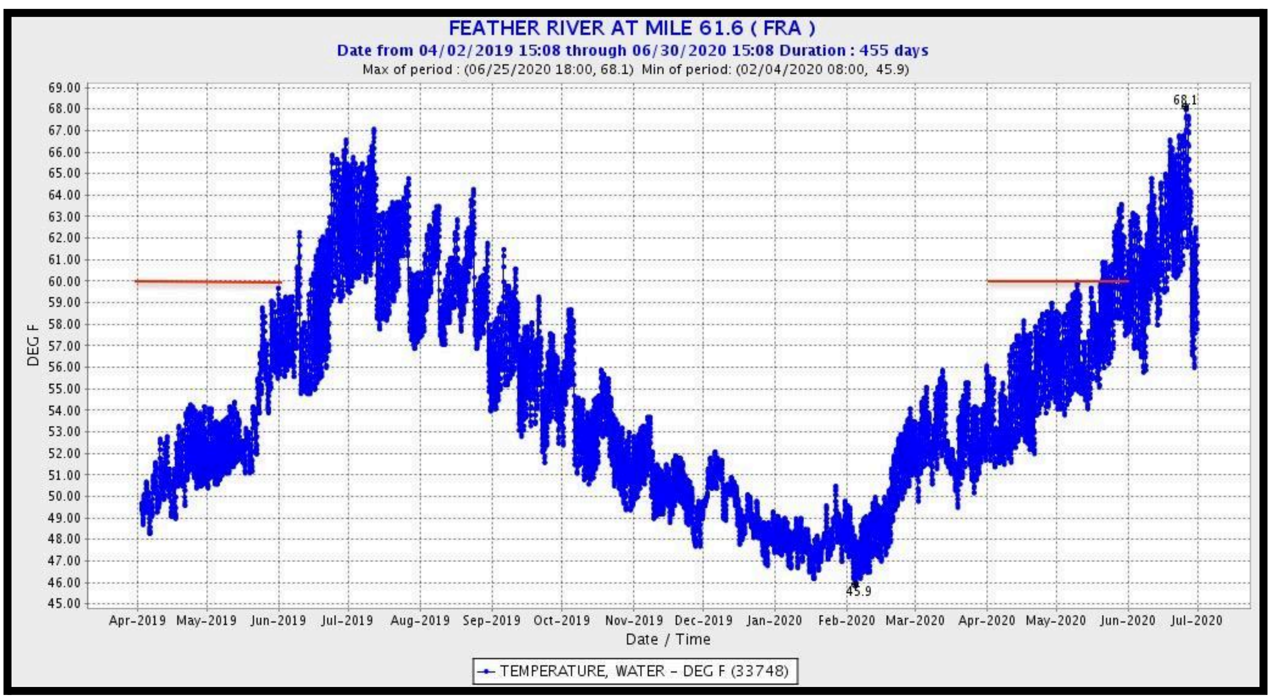

Figure G-10. Hourly water temperatures in the lower Feather River upstream of Afterbay inlet in the low-flow section Apr 2019 to July 2020 (2019 was wet year, 2020 was a below normal water year). Note red lines where water temperatures exceeded recommended 60°F in Apr-May period.

- *Barriers to Migration* (p31)

- *Barriers to migration caused by impoundments were recognized as a High threat to adult sDPS in the SRB, with high data sufficiency. Large dams constructed on the Sacramento, Feather, and Yuba rivers have restricted spawning and rearing areas for the sDPS by presenting a physical barrier to migration (see Distribution section above and Figure 3). Impassible barriers were recognized as a main threat to the sDPS in the original listing decision as well as in subsequent status reviews. These barriers, along with water management actions that divert water for other uses and restrict water at certain times of year, affect river flow volumes and temperatures throughout the year. As described in sections above, flow may be an important cue for migration and can factor into successful spawning, egg deposition, and early life stage development.*

  Comment: We have given this factor a Number 2 rating (see Figure 7) because only the spawning portion of the populations migrates up the river each year, whereas other factors with a Number 1 rating affect the entire population or brood year production. Both the Number 1 and 2 factors can have a large impact on the populations depending on the circumstances and are thus important to address in a recovery plan.

- *In the mainstem Sacramento River (Figure 3), the decommissioning of RBDD in 2013 was an important step in barrier removal, as the sDPS could reach spawning areas above RBDD during all months of the year (Steel et al. 2018). The next significant barrier on the mainstem for the sDPS is the ACID Dam, followed by Keswick and Shasta Dams. ACID Dam may be a passage barrier to address in recovering the sDPS. Currently, the fish ladder at the ACID Dam is not adequate for sturgeon passage.*

  Comment: We recommend green sturgeon passage at the ACID Dam through its use as a segregation weir. Green sturgeon can be trapped and hauled above the dam or sturgeon passage facilities be constructed at the dam. We recommend maintaining water temperatures below 60ºF at ACID Dam and downstream to Red Bluff in spring.

- *Farther downstream, the Yolo and Sutter bypasses can also serve as a barrier to sDPS migration during high water events (Thomas et al. 2013). During some high flow events, adult green sturgeon enter the Yolo and Sutter bypasses and become stranded when the water recedes. In some cases, adult sturgeon remain stranded in small isolated bypass ponds through the summer or fall, making them extremely vulnerable to poaching and other sources of mortality. In 2011, 24 sDPS were rescued from the Yolo and Sutter bypasses (Thomas et al. 2013). Since relocation efforts cannot prevent all mortality associated with stranding, and the loss of even a few adult fish periodically should be avoided, it is important to construct structures at these weirs that allow volitional passage of upstream migrating green sturgeon. (p31).*
- *The Sacramento Deep Water Ship Channel can also block migration. There are multiple upriver migration routes through the lower Sacramento River that either lead to the middle Sacramento River and Feather River or terminate in areas with no upriver passage (e.g., Fremont Weir). The Sacramento Deep Water Ship Channel terminates at closed locks in the City of West Sacramento that separates the ship channel from the Sacramento River. These locks are approximately 32 kilometers upstream from open migration routes to spawning habitat and it is uncertain how long fish encountering the closed locks search for open routes and resume normal migration.* (p32)

Comment: Both bypasses often flow strong in winter-spring from their own watershed precipitation which may attract sturgeon into their lower entrances and lead to subsequent stranding. Gated entrances that allow sturgeon passage are recommended at each overflow weir in the Sacramento River Valley flood control system. The gates should be capable of providing some non-flood flow to attract sturgeon to the gate exits that is sufficient to allow passage or at least a trapping capability. Such a system has been built at the exit to the Colusa Basin Drain at the exit into the Yolo Bypass. The entrance to the Ship Channel should be repaired to allow sturgeon to pass freely into the Sacramento River.

- *In the Feather River, the boulder weir at Sunset Pumps is the first potential barrier encountered by migrating adult sDPS (Figure 3). The weir creates a partial barrier to adult sDPS migration to the only confirmed spawning location in the Feather River (Seesholtz et al. 2015).* (p32)

  Comment: We recommend the boulder weir be modified to pass sturgeon.

- *On the Yuba River, Daguerre Point Dam is the lowermost barrier (Figure 3). It was built to trap mining debris in the river and is now filled with sediment. The current function of the dam is to maintain a suitable river elevation for a gravity–water fed diversion. It serves as a complete barrier to sDPS migration, followed by Englebright Dam upstream. Water diversions associated with Daguerre Point Dam also influence the flow regime in the Yuba River, potentially further affecting the sDPS.*

  Comment: A bypass channel is proposed to pass sturgeon around the dam. In the event this is not feasible, sturgeon may be trapped or netted an

H. White Sturgeon Spawning in the San Joaquin River, California, and Effects of Water Management (Jackson et. al. 2016)

- *Collections of fertilized eggs, coupled with hydrology data, confirm that white sturgeon spawned within one and four sites in the San Joaquin River during wet (2011; n = 23) and dry (2012; n = 65) water-year conditions. Small pulse flow augmentations intended to benefit juvenile salmonids appear to have triggered white sturgeon spawning within this system. Understanding the effects of water management on spawning and subsequent recruitment is necessary to increase white sturgeon recruitment to the San Francisco Estuary.*
- *The collection of white sturgeon eggs in 2011 and 2012 provided the first evidence of white sturgeon spawning in the San Joaquin River. The eggs collected were likely part of at least seven separate spawning events based upon capture location, date of capture, water temperature, stage of develop- ment, and the estimation that it takes a female up to 21 h to complete oviposition (Van Eenennaam et al. 2012). Our estimation of the number of spawning events is likely conservative as the recovery of eggs from a single spawning event was quite rare in this study.*
- *Researchers (e.g., Kohlhorst 1976; Schaffter 1997) have speculated that the presence of white sturgeon in the San Joaquin River was a result of fish on a spawning migration during years with high runoff (i.e., wet water- year types). Spawning surveys in 2011 and 2012 occurred during two drastically different water-year types. Mean daily streamflow in the San Joaquin River during early 2011 was as much as four times higher than mean daily streamflow for water years 1993 to 2012 (Figure 3). As speculated, streamflow levels of this magnitude may have triggered white sturgeon to enter and spawn within the San Joaquin River. However, streamflow levels in 2012 were generally half or less than the 20-y average. Despite much lower than average streamflow during early 2012, we observed at least six spawning events, demonstrating that spawning also occurs in dry years.*
- *We collected 23 eggs over a 4-d period at rkm 142 in 2011. Water temperatures during the incubation period ranged from 14.6 to 15.88C and were consistent with optimal white sturgeon spawning temperatures observed on the Columbia and Sacramento rivers, 10 to 18C and 14 to 16C, respectively (Kohlhorst 1976; Parsley et al. 1993; McCabe and Tracy 1994).*

  Comment: We have recommended small pulse flow augmentations in the San Joaquin River that along with improved water temperatures in spring may benefit sturgeon reproduction in the San Joaquin River. We also recommend 65ºF (18 ºC) water temperatures in the three main tributaries in in April and May, which should provide some spawning habitat conditions for sturgeon in the San Joaquin River below each tributary in wet years when sturgeon may be attracted to the San Joaquin River.

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I. Summer Bay Algae Blooms

Dead sturgeon were noted in the Bay in 2022 and 2023[3]. Algae blooms were deemed the cause through toxins or hypoxia from low dissolved oxygen after bloom die-offs in association with abnormally warm water temperatures from draining of the Delta during Super Moon cycles.

- Sturgeon Moon August 1, 2023 ([August 9, 2023](#))

It is August 2023, and the month will feature two "Super Moons." The first full moon is called a "Sturgeon Moon," originally coined in reference to the ease of catching sturgeon in the Great Lakes during a full moon in summer.[1] Its cycle began with the quarter moon and neap tide on July 24 until the full moon on August 1.[2] This year's Sturgeon Moon was regrettably prophetic in that it coincided with a new sturgeon die-off in San Francisco Bay in summer 2023.

Last summer, there was a die-off of nearly a thousand adult white sturgeon in the greater San Francisco Bay due to a toxic algae bloom. More dead white sturgeon adults have been showing up on Bay beaches again this summer.[3] After analyzing data related to the die-off, I now blame the white sturgeon die-off on the Sturgeon Moon (i.e., the tides) and some complicit factors.

Why are toxic algae blooms occurring, and sturgeon dying, again this year, in a wet flood year? Toxic blooms are not supposed to occur in wet years.

Based on the information available, this summer's die-off event is occurring during a Sturgeon Moon. The Sturgeon Moon cycle (that occurred in late July and early August this year around the August 1 full moon) causes the Delta to rapidly fill from the Bay and stop flowing (termed a spring tide). In the recent heat, all that water in the Delta and lower rivers heated up to 75ºF. Then the Sturgeon Moon cycle drained (neap tide) the Delta into the Bay. When the top three feet or so of warm Delta water all drained into the Bay, it triggered the toxic algae bloom, low oxygen, and hot water. In combination, these factors are killing the fish.

Sturgeon likely suffered their initial stress from the warm lower rivers where they spawned in May. By the time of the Sturgeon Moon, many had moved downstream into the Delta toward the cooler Bay. The emptying of the warm Delta into the Bay during the neap tide likely stimulated further movement into the Bay. Once in the Bay, the stressed sturgeon received added stress from the warm Bay and its new toxic algae bloom and hypoxia conditions. The accumulated stress from the whole series of events likely caused the die-offs observed in the past two summers.

Yes, the Sturgeon Moon, Bay pollution, and algae seeds from last year's bloom played a part, but the biggest culprits were state and federal water managers, who allowed the rivers and

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[3] https://www.dailykos.com/stories/2023/8/11/2186683/-Sturgeon-are-dying-again-as-algae-bloom-hits-San-Francisco-Bay-and-Delta-water-exports-amp-up?pm_campaign=blog&pm_medium=rss&pm_source=Dan%20Bacher , https://waterboards.ca.gov/sanfranciscobay/water_issues/programs/HABs/LakeMerritt_Report_ADA.pdf

Delta to heat up in early summer by making high water deliveries upstream of the Delta and exporting high volumes of water from the Delta.
I worry about the accuracy of the loss estimates of adult white sturgeon in the Bay. As noted in the Chronicle article cited and linked above, there may be many dead sturgeon that have gone undetected at the bottom of the Bay. Last year, as many as 1000 sturgeon were found dead. There are probably less than 10,000 adult white sturgeon left in the Bay-Delta spawning population. Sport fishermen generally harvest about a thousand each year. The California Department of Fish and Wildlife and the California Fish and Game Commission are revisiting fishing regulations this fall and may close or restrict the popular sport fishery.[4]

Could these circumstances have been avoided? Yes. First by maintaining lower Sacramento River and Delta inflow temperatures (Figure 1) at or below the state water quality standard of 68ºF (20ºC) with adequate flows (greater dam releases and/or less water deliveries). The lower Sacramento River flow of 5000 cfs is far too low for early summer, especially in a wet year. Second, by maintaining Delta temperatures at least in the 20-22ºC range (there is no Delta water temperature standard) with adequate cool inflows. Third, by maintaining water temperatures in Bay below 20ºC with adequate cool Delta outflow during the spring tides. This solution would have been difficult to achieve in drought year 2022, but not in flood year 2023.

Water project managers should have foreseen the tidal patterns coming in the summer (Figure 2) and the inadequacy of the estimated flows they were providing to the Delta (Figure 3). Measured Delta outflow by USGS was actually lower than the DWR model predictions (Figure 4). Instead, water managers provided approximately 20,000 cfs of water deliveries, including near-maximum export pumping from the Delta (Figure 5). The upstream pull to the south Delta export pumps reached a peak near 10,000 cfs in interior Delta channels at the end of July (Figure 6).

The influx of warm water reached a peak at the maximum ebb tide on July 24. This can be seen in Figure 7 at the Carquinez Bridge gage, and Figure 8 in Suisun Bay. Evidence of the Bay bloom can be seen in Figure 9, as the North Bay water returned to the East Bay with its algae (chlorophyll) concentrations and low dissolved oxygen at the end of July, coinciding with the return of the spring tide. Further evidence of the bloom is indicated in Figure 10 in the low nitrogen concentrations at the end of July in Suisun Bay.

In summary, the recent reappearance of a die-off of white sturgeon in the Bay appears to have been triggered by the strong tides of the summer Sturgeon Moon draining warm water from the Delta into the Bay. The warm water, in turn, was the result of excessive water diversions upstream of the Delta and near-maximum water exports from the Delta, combined with tidal dynamics.

Footnotes:

1. *Two supermoons will light up the night sky in August. Here's what you need to know https://www.sfchronicle.com/bayarea/article/supermoons-two-blue-sturgeon-18270736.php* ↩
2. *Spring tides always happen when the Moon is at the full or new phase, which is when the Sun, Moon and Earth are in alignment. Neap tides occur around the first and last quarter phase of the Moon, when the Moon's orbit around Earth brings it perpendicular to the Sun.* ↩
3. *https://www.sfchronicle.com/climate/article/fishkill-18279379.php* ↩

4. https://ncgasa.org/2023/04/17/white-sturgeon-meeting-and-overview-from-cdfw/↩

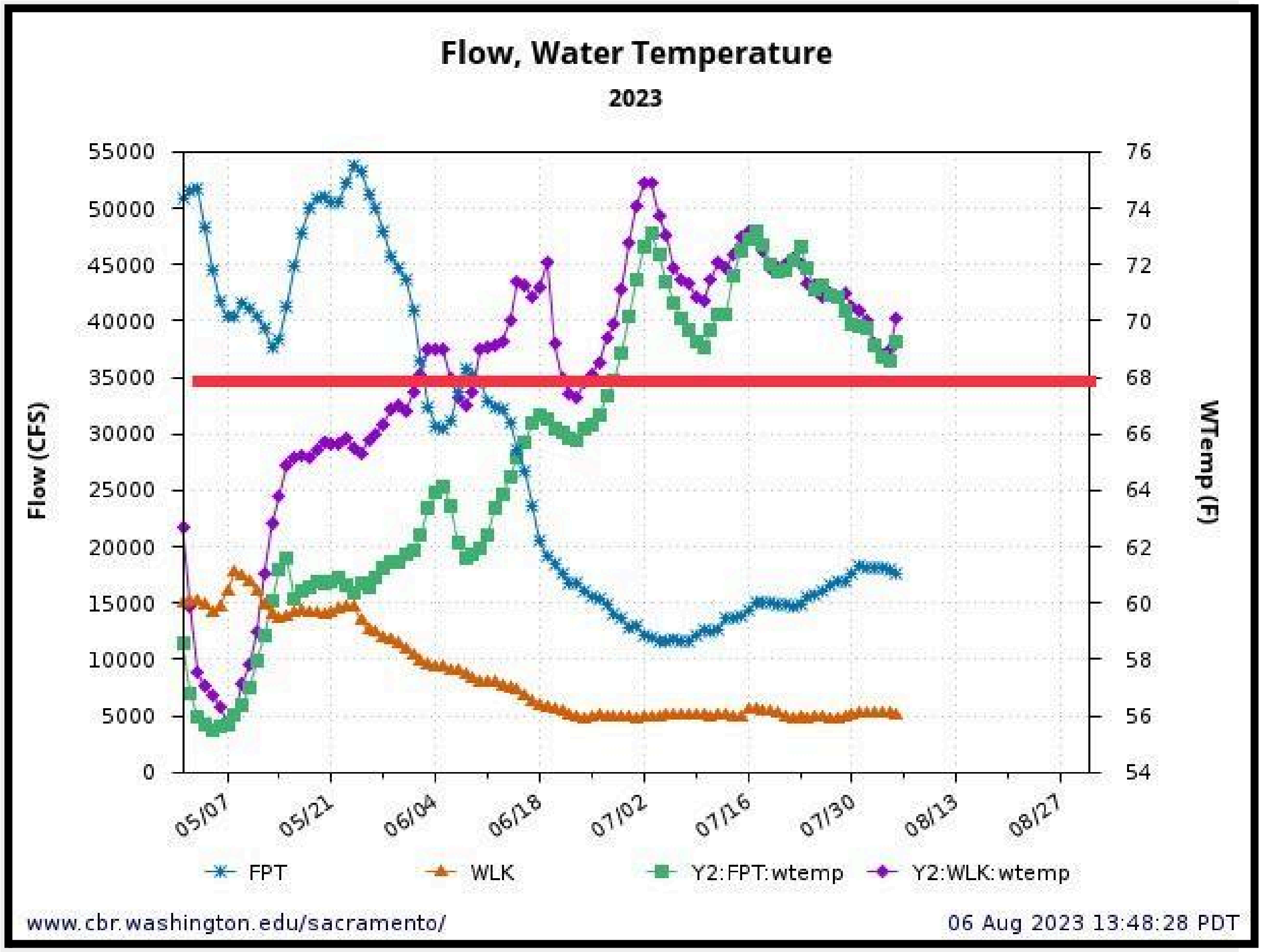

Figure 1. Flow and water temperature in the lower Sacramento River upstream of the Delta at Wilkins Slough (WLK) and at the entrance to the tidal Delta at Freeport (FPT). Red line is water quality standard for lower Sacramento River.

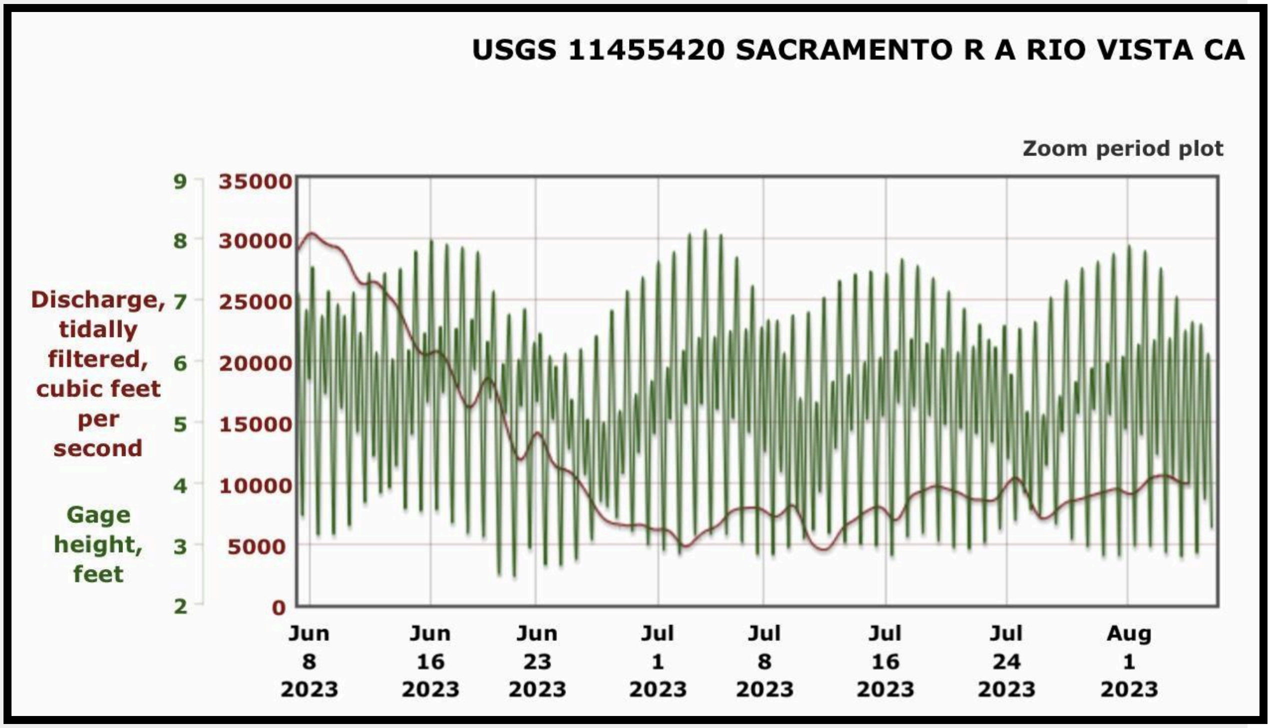

Figure 2. Average daily flow and hourly stage at Rio Vista in North Delta near exit to the Bay. Note the sharp flow increase and the drop in stage on 7/24 (Delta draining under the neap tide of the initial quarter of the Sturgeon Moon.)

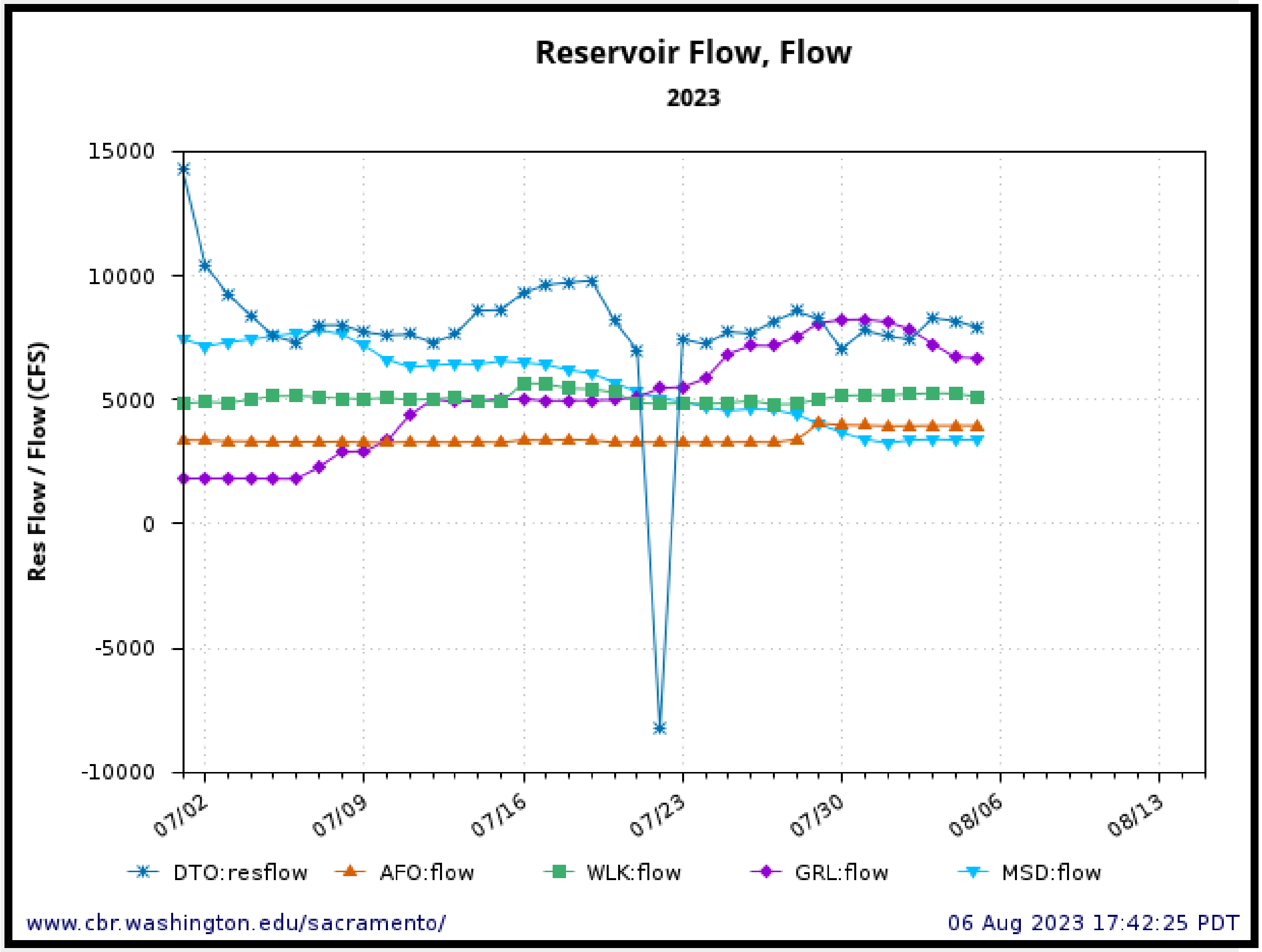

Figure 3. Stable Delta conditions in July 2023. Inflows = (American River AFO + Lower Sacramento River at Wilkins Slough WLK + lower Feather River at Gridley GRL + lower San Joaquin River at Mossdale MSD. Outflow (DWR-DTO) = Inflow – exports. Note relatively stable conditions. Note DWR outflow is calculated (not measured) from daily flows.

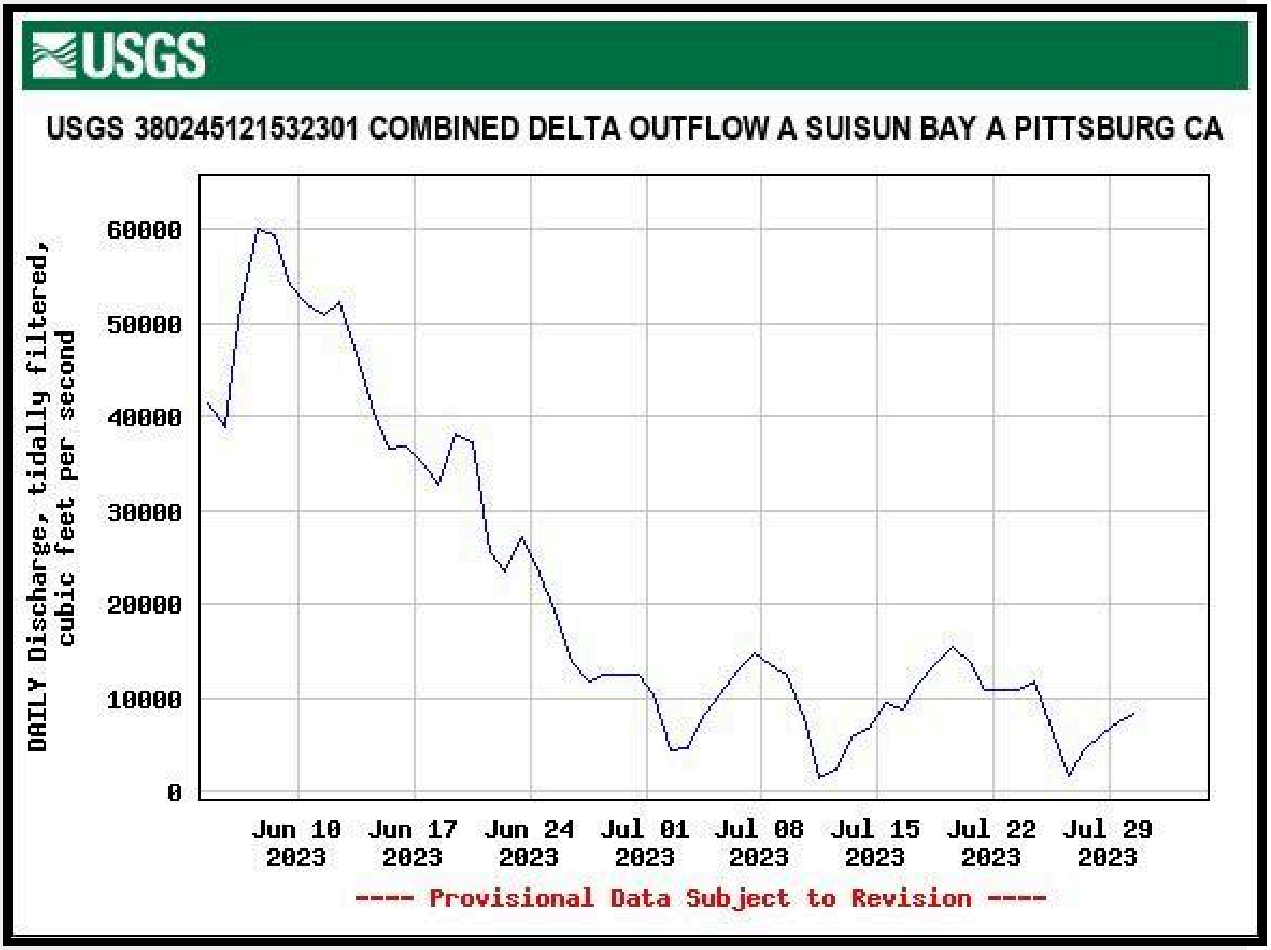

Figure 4. Delta outflow as estimated by USGS from flow gages. Note drop in Delta outflow (at the peaks in spring tides) beginning on 7/24 as shown in Figure 2, but not in Figure 3. Also note the peak outflows were higher in USGS outflows.

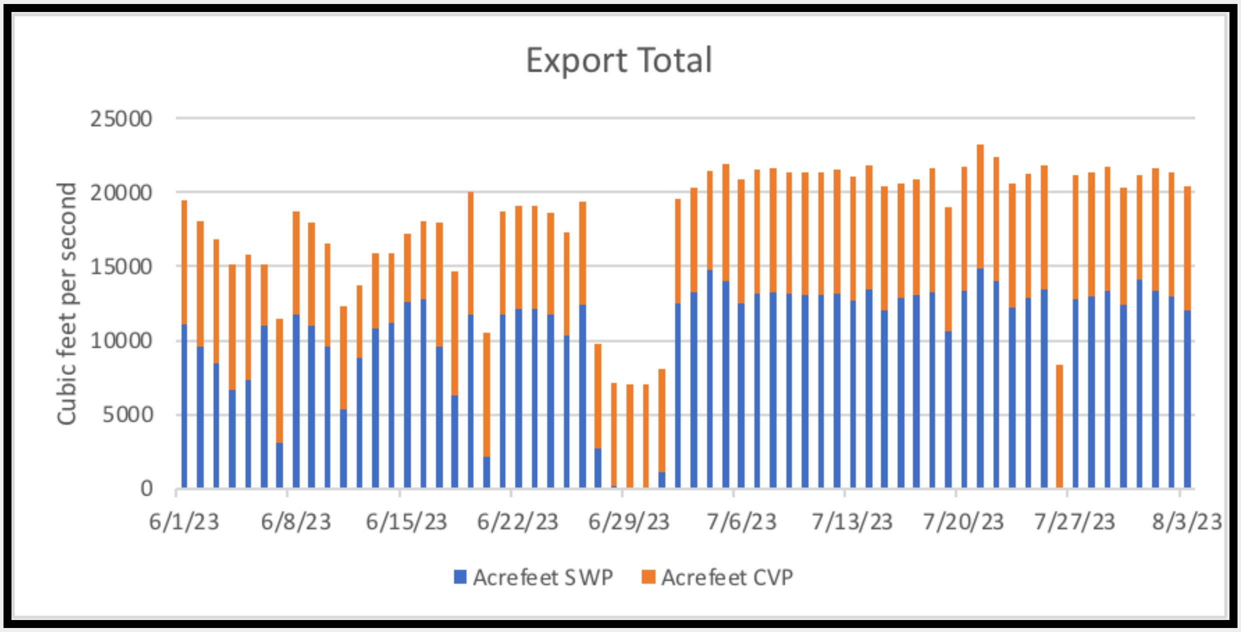

Figure 5. South Delta SWP and CVP exports June-July 2023. Note 20,000 acre-ft per day is approximately hourly average of 10,000 cfs. Maximum export rate is 11,400 cfs (approximately 23,000 acre-ft per day).

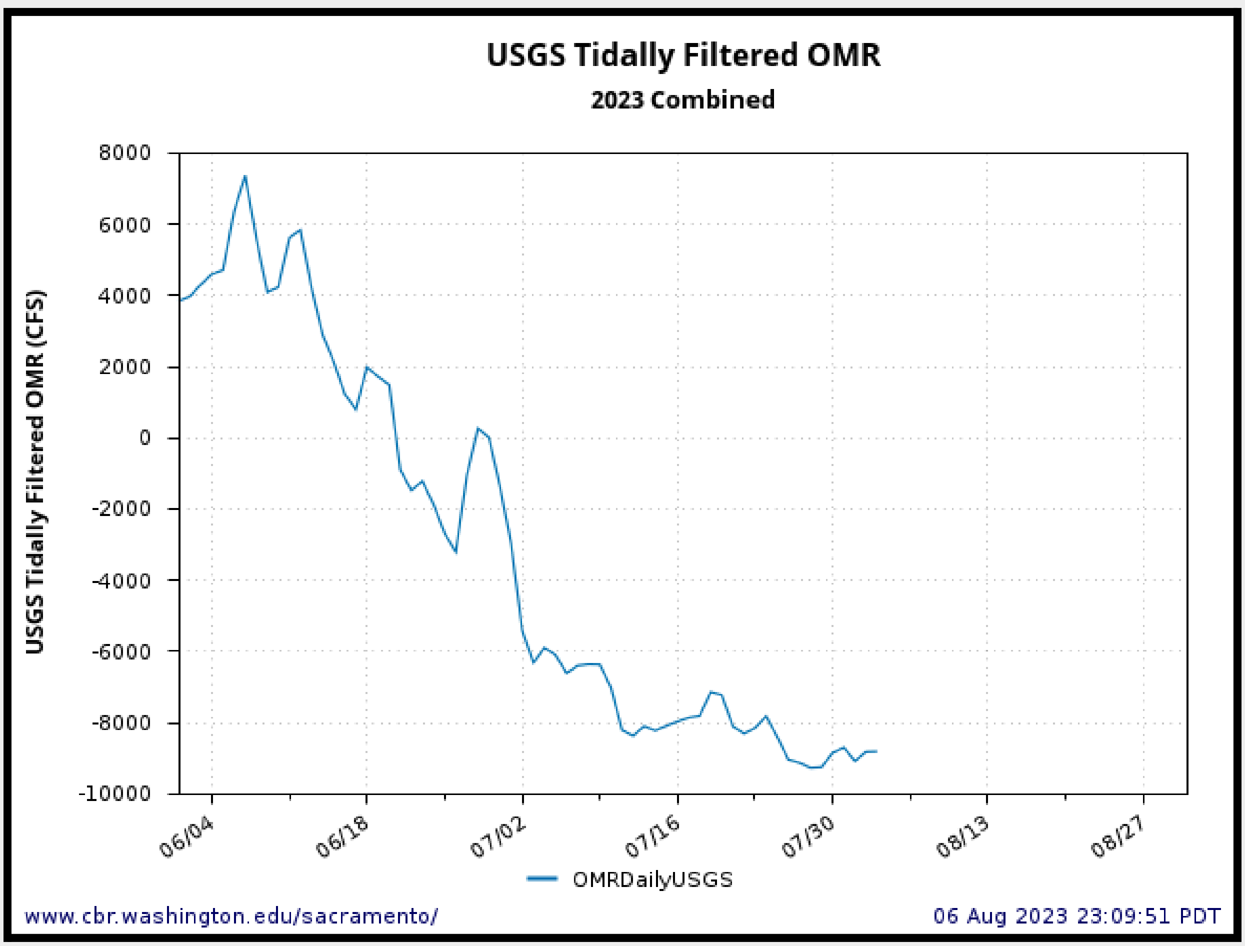

Figure 6. Old and Middle River flows toward export pumps in south Delta.

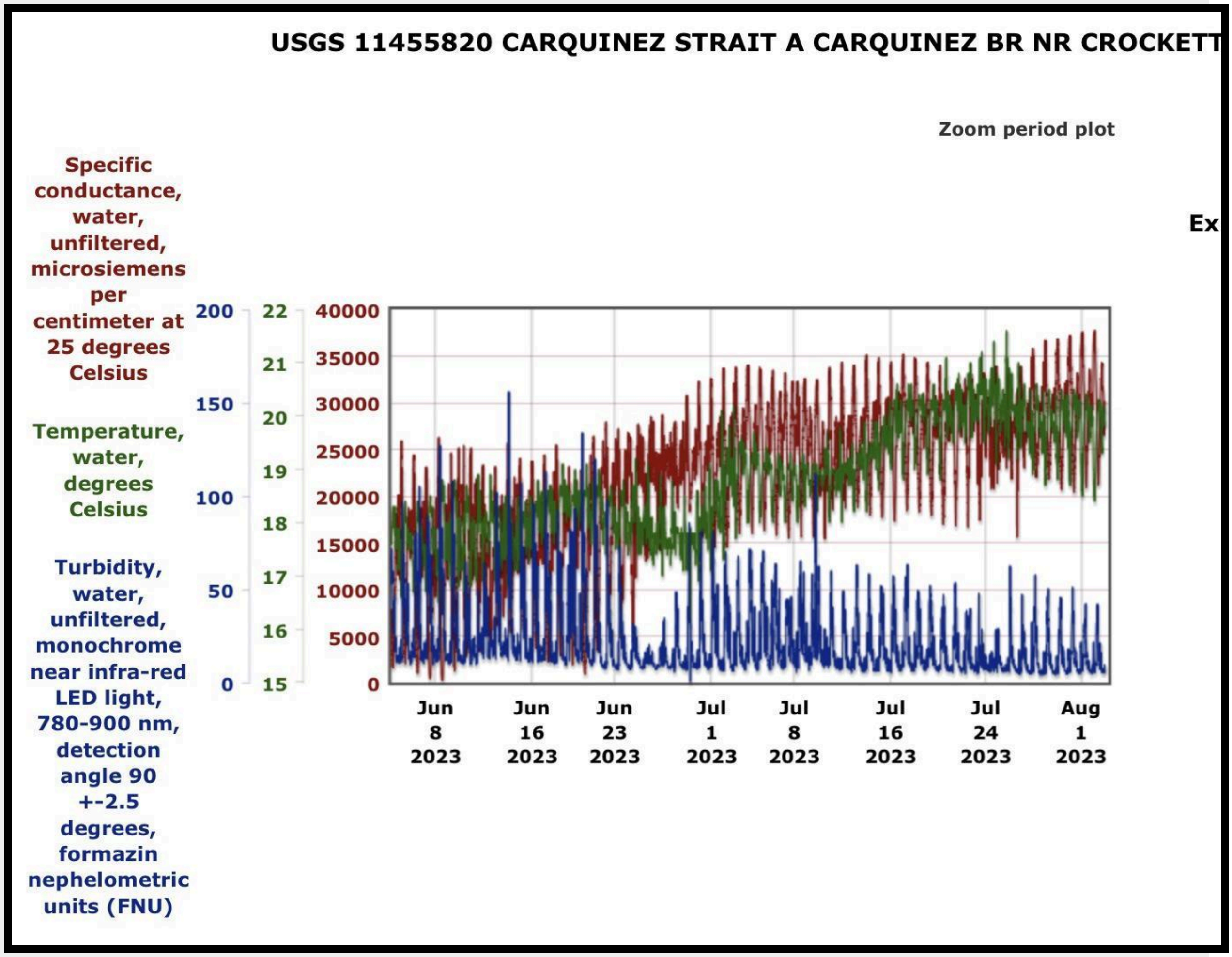

Figure 7. Salinity (EC), water temperature (C), and turbidity at Crockett in north Bay in June-July 2023. Note neap tide and lower salinity, warm, clear water on 7/24-25.

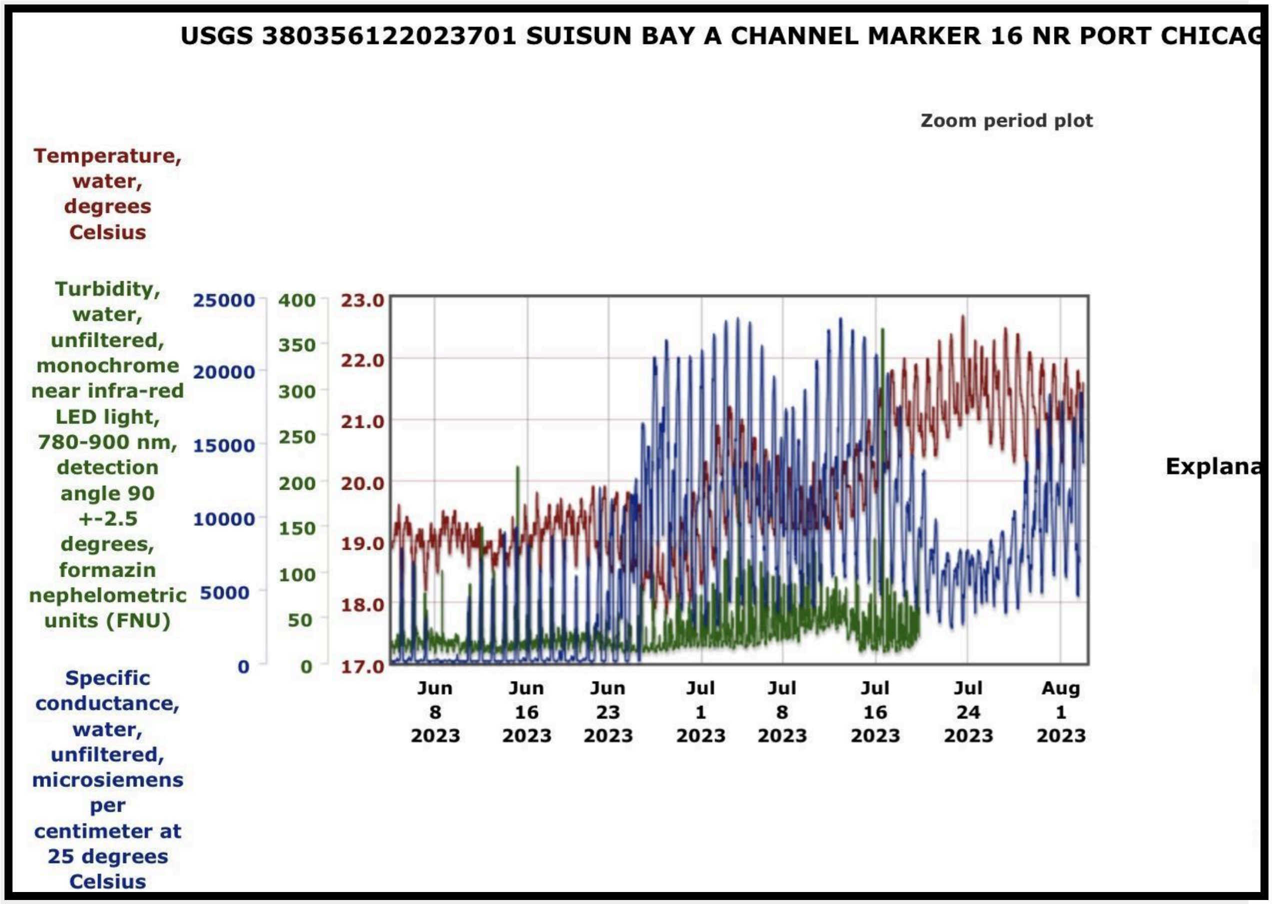

Figure 8. Salinity (EC), water temperature (C), and turbidity at Port Chicago in east Bay in June-July 2023. Note neap tide and lower salinity and warmer water on 7/22-25.

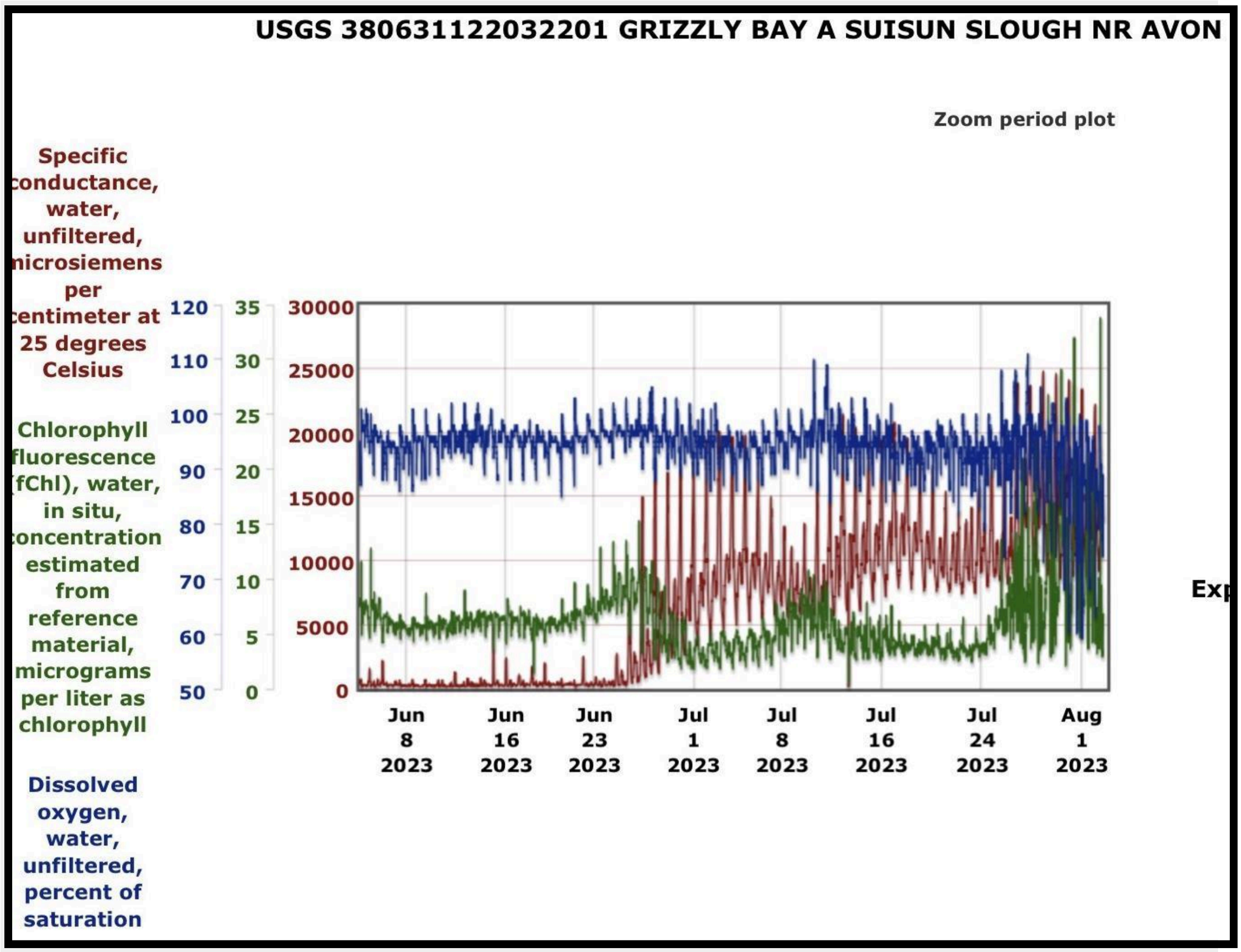

Figure 9. Salinity (EC), dissolved oxygen, and chlorophyll concentration in east Bay in June-July 2023. Note bloom, higher salinity, low dissolved oxygen beginning on 7/25.

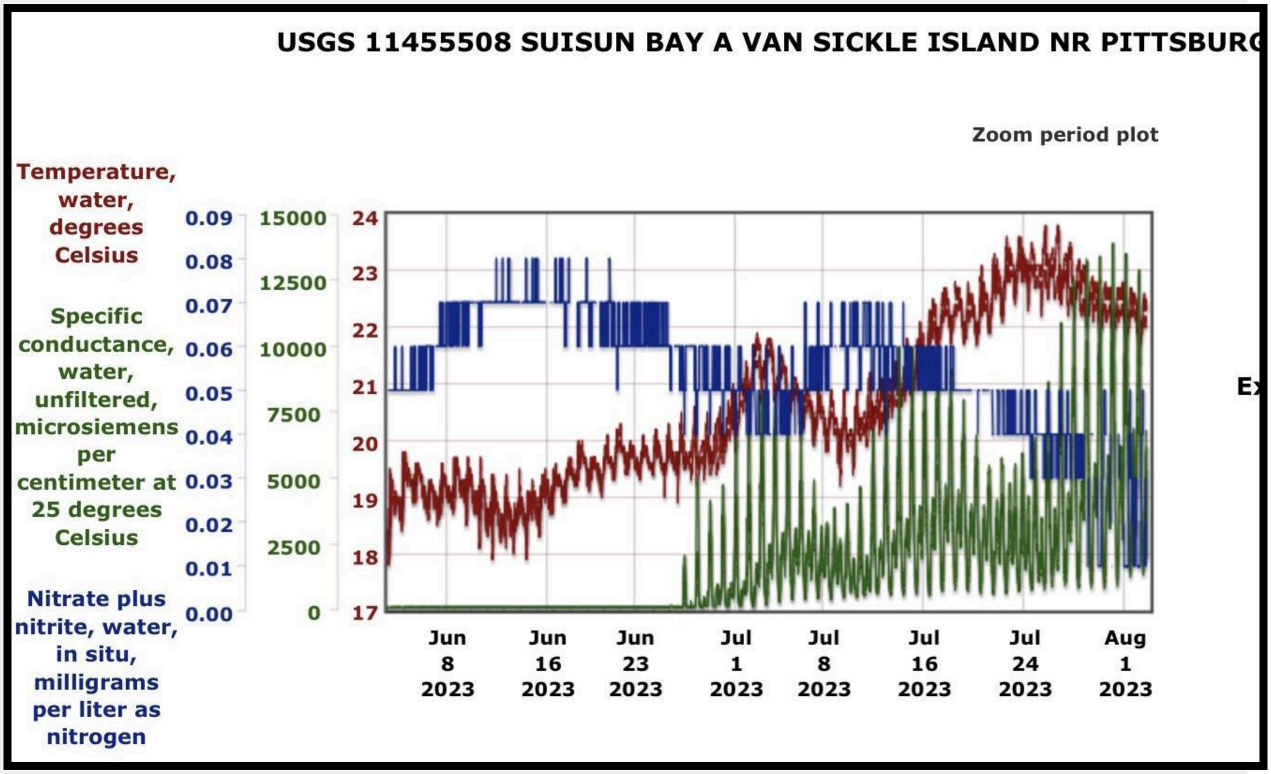

Figure 10. Salinity (EC), water temperature (C), and total nitrogen at Pittsburg in east Bay in June-July 2023. Note higher salinity and water temperature, and reduced nitrogen (from algae uptake) beginning on 7/24-25.

- Sturgeon Moon 2 – August 30 August 12, 2023

In an August 9 post, I described the effects on San Francisco Bay and its sturgeon from the August 1 Sturgeon Moon. I hypothesized that the draining of warm water from the Delta into the Bay over several days of the strong neap tide during the Sturgeon Moon caused an algae bloom and unseasonably warm water in the Bay (Figure 1) that was killing sturgeon, as it had in summer 2022. I blamed the warm water on low river flows and high water diversions in the Central Valley that caused the Delta to reach 75°F and the Bay to subsequently reach an unprecedented 72-73°F. The warm water, abundant sunshine, and generally high nutrients caused the bloom and the low dissolved oxygen levels that resulted in fish dying.

These events are about to reoccur with the August 30 Super Moon. Once again, warm water will drain from the Delta on several days of strong neap tides the week before the Super Moon (probably around August 24). The bloom should appear about August 28, about two days before the full moon.

The key question is how warm the Delta will be when it drains into the Bay. This depends on air temperatures, river flows, and Delta outflow (the product of reservoir releases, Delta inflow, and water diversions). With an expected general heat wave August 14-17, there is reason to be concerned that water draining from the Delta could be warm once again.

There have been several mitigating factors since the August 1 Super Moon. Reservoir releases have increased slightly over the past month (Figure 2). The strength of the spring and neap tides has decreased slightly following the August 1 full moon (Figure 2). Higher Delta inflows (Freeport) have reduced Delta water temperatures slightly (Figure 3).

To minimize the strength of the potential bloom, warming, and fish die-off in the Bay, it is essential to keep Delta water temperatures down before the August 25-26 neap tide. Several interdependent actions come to mind: (1) Increase lower Sacramento River flows over the next 10 days by several thousand cfs to get Wilkins Slough water temperatures down to about 68°F. (2) Ensure that the extra Wilkins flow reaches the Delta at Freeport to keep Delta inflow up several thousand cfs. (3) Increase Delta outflow during the August 22-24 spring tide by reducing south Delta exports, to minimize the build-up of warm water in the Delta prior to when the Delta drains to the Bay on the August 25-26 neap tide.

These actions will hopefully minimize the damage caused by Central Valley water management to the Bay ecosystem and specifically to the white sturgeon population during the next Super Moon cycle.

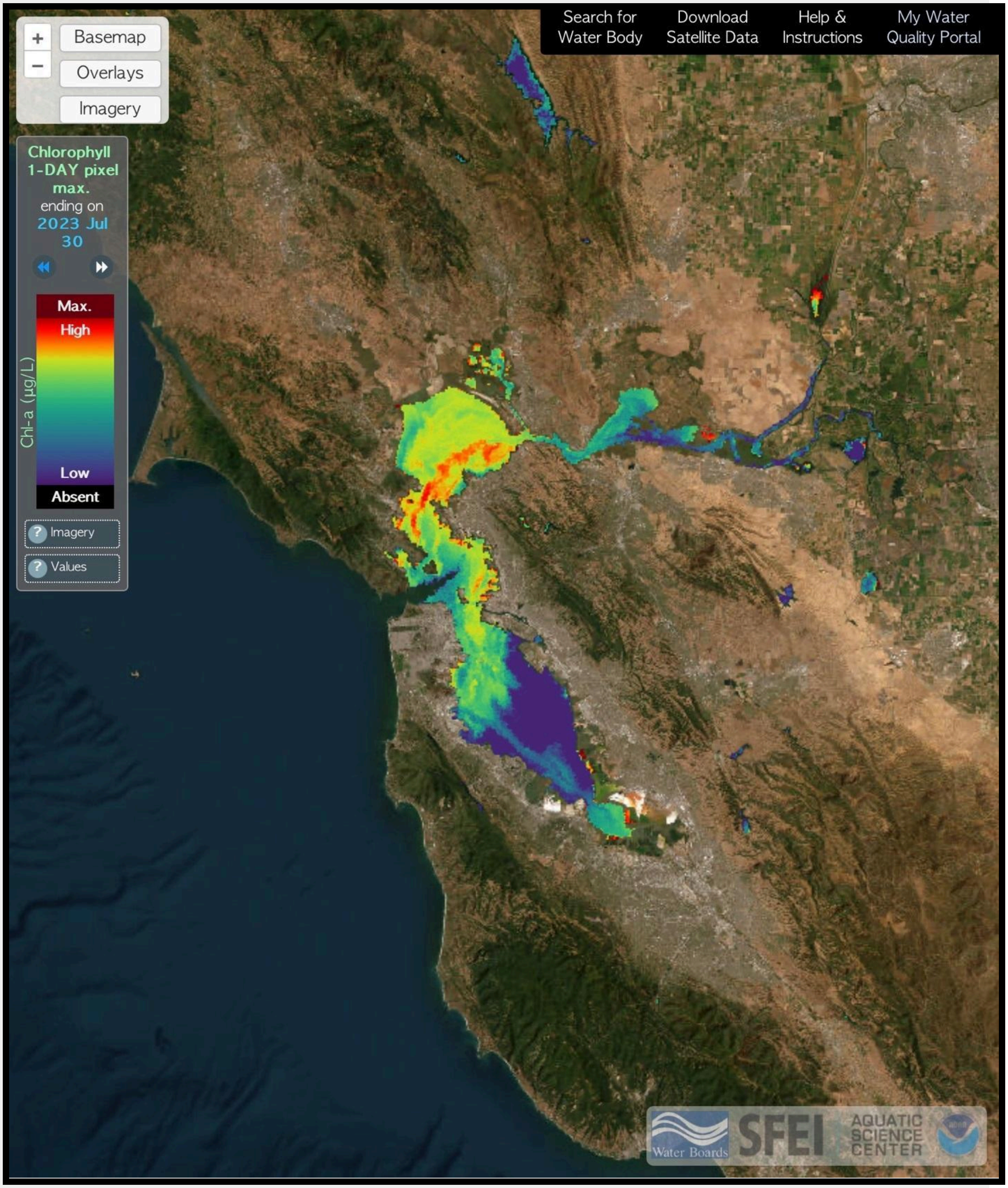

Figure 1. San Francisco Bay algae bloom on July 30, 2023. [Source]

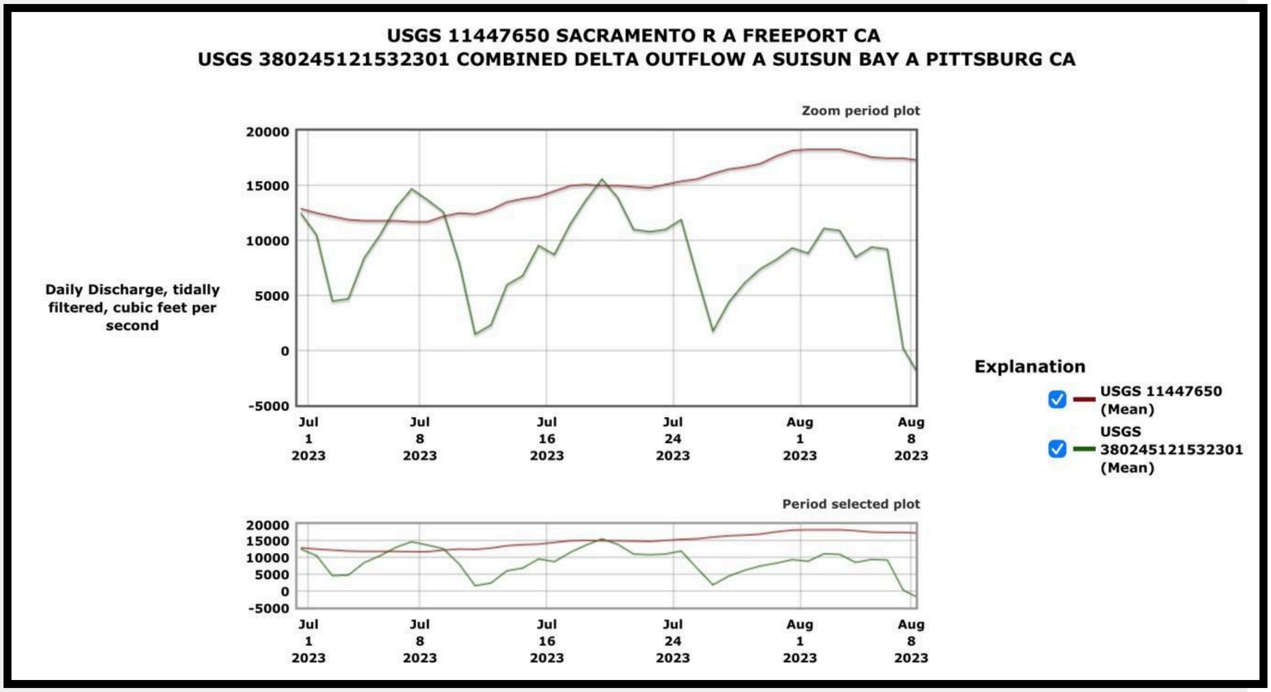

Figure 2. Delta inflow (Freeport) and Delta outflow to Bay in week since the August 1 Super Moon. Note the spring tide has gotten slightly stronger and Delta inflows have increased (due to increased Folsom and Oroville reservoir releases)

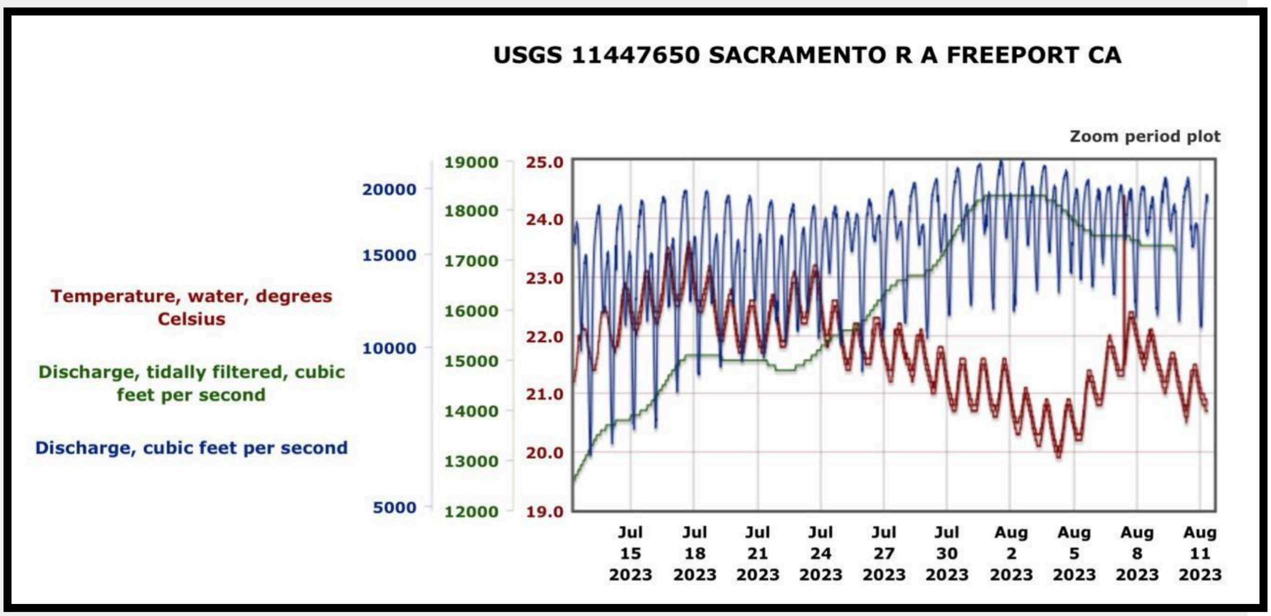

Figure 3. Delta inflow (tidally filtered and hourly) from the Sacramento River and water temperature at Freeport July-August 2023.

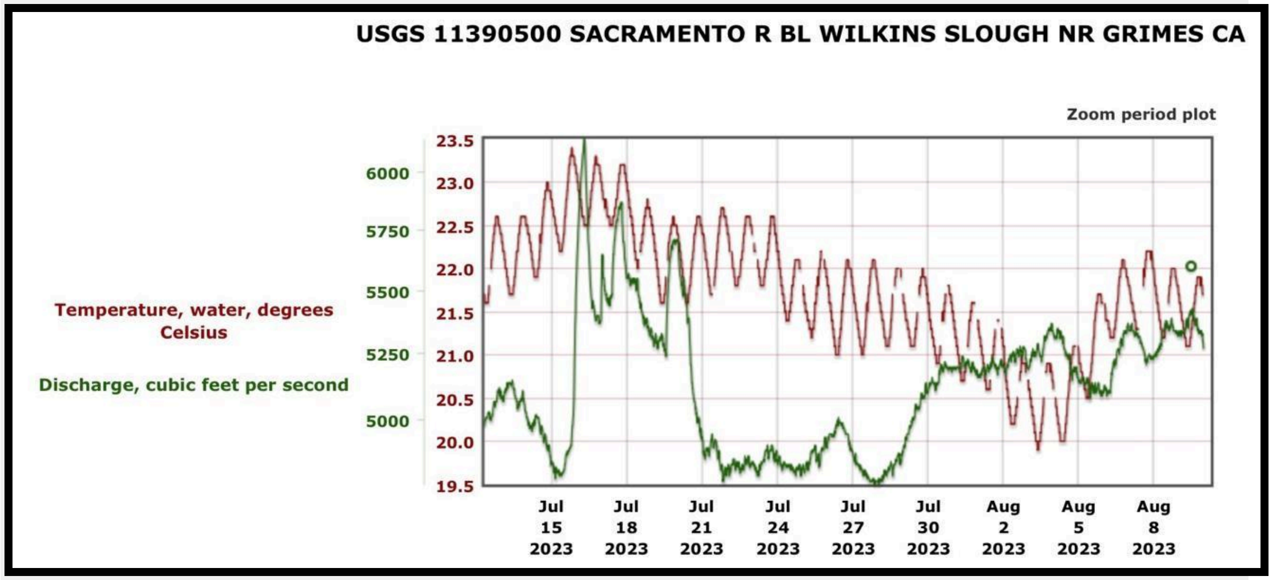

Figure 4. Lower Sacramento River streamflow and water temperature at Wilkins Slough gage July-August 2023. Water temperature remains high (>20°C, 68°F) under low streamflow.

- Sturgeon Moon #3 – August 30 Blue Moon September 4, 2023

August 2023 has come to an end, following the second "Super Moon" of the month – a Blue Moon. The first full moon of the month was called a "Sturgeon Moon," originally coined in reference to the ease of catching sturgeon in the Great Lakes during a full moon in summer. The cycle began with the quarter moon and neap tide on July 24 until the full moon on August 1.[1]

This year's Super Moons have made a mess of San Francisco Bay, as they did in summer 2022. This year's August moons have again, regrettably, led to a die-off of sturgeon and other Bay fish.[2] *The Super Moons' strong tides caused warm water from the Delta to drain into the Bay, making the usually cool Bay unseasonably warm. (The ocean Blob may have added to some of this summer's warm Bay water.) The warm water and the associated algal blooms (and their die-offs) have led to unprecedented low dissolved oxygen levels in the Bay, which can kill fish.*

While the degree of harm has not been as bad as last year's summer blooms that were aggravated by the 2022 drought, this year's algal blooms have also harmed fish despite generally beneficial wet-year conditions. Last summer, there was die-off of nearly a thousand adult white sturgeon in the greater San Francisco Bay due to algal blooms. More dead white sturgeon adults also showed up on Bay beaches again this summer.[3]

The Bay turned warmer under this summer's Super Moons than under those last summer (Figure 1). Blooms are still happening, as indicated by high turbidities and chlorophyll levels in portions of the Bay (Figures 1-3). The draining of warm Delta water to the Bay just before the 2023 Super Moons (Figures 4 and 5) warmed the Bay (Figure 6). Low dissolved oxygen continues to plague the Bay (Figure 6). The most recent 2022 bloom is depicted in Figure 7.

The summer 2023 Super Moons and their algal blooms make a complicated story, with the effects of various factors implicated in the blooms (Figure 8), and their role in fish die-offs in the Bay, yet to be fully determined. My concern centers on how warm the Delta becomes in summer before it drains into the Bay during the lunar tidal cycles. The lower rivers and Delta received too little flow from major Central Valley reservoirs for a wet year with full reservoirs. This is an increasing trend (Figure 9) that deserves a lot more attention to ensure protection of the Bay's fish and other public trust values. Otherwise, the trend will simply be chocked up to climate change.

Footnotes:

1. Spring tides always happen when the Moon is at the full or new phase, which is when the Sun, Moon and Earth are in alignment. Neap tides occur around the first and last quarter phase of the Moon, when the Moon's orbit around Earth brings it perpendicular to the Sun. ↩
2. https://calsport.org/fisheriesblog/?p=4398 ↩
3. https://www.sfchronicle.com/climate/article/fishkill-18279379.php ↩

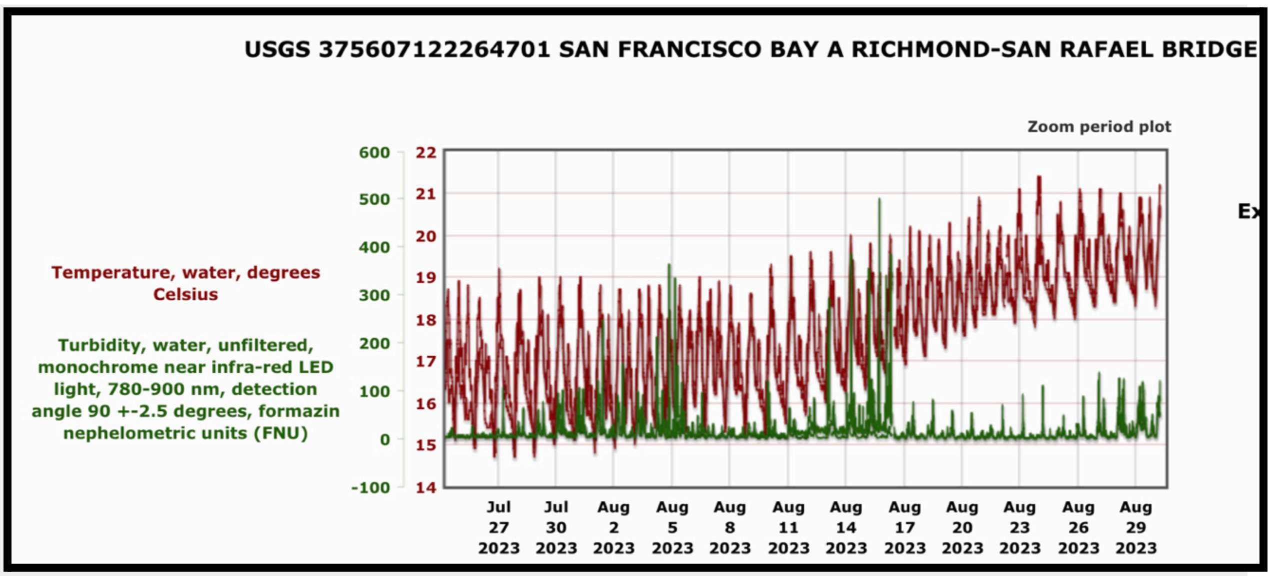

Figure 1. North Bay (San Pablo Bay at Richmond Bridge) water temperature and turbidity in summer 2023. Note the presence of the three blooms indicated by high turbidity levels (>100 FNUs)

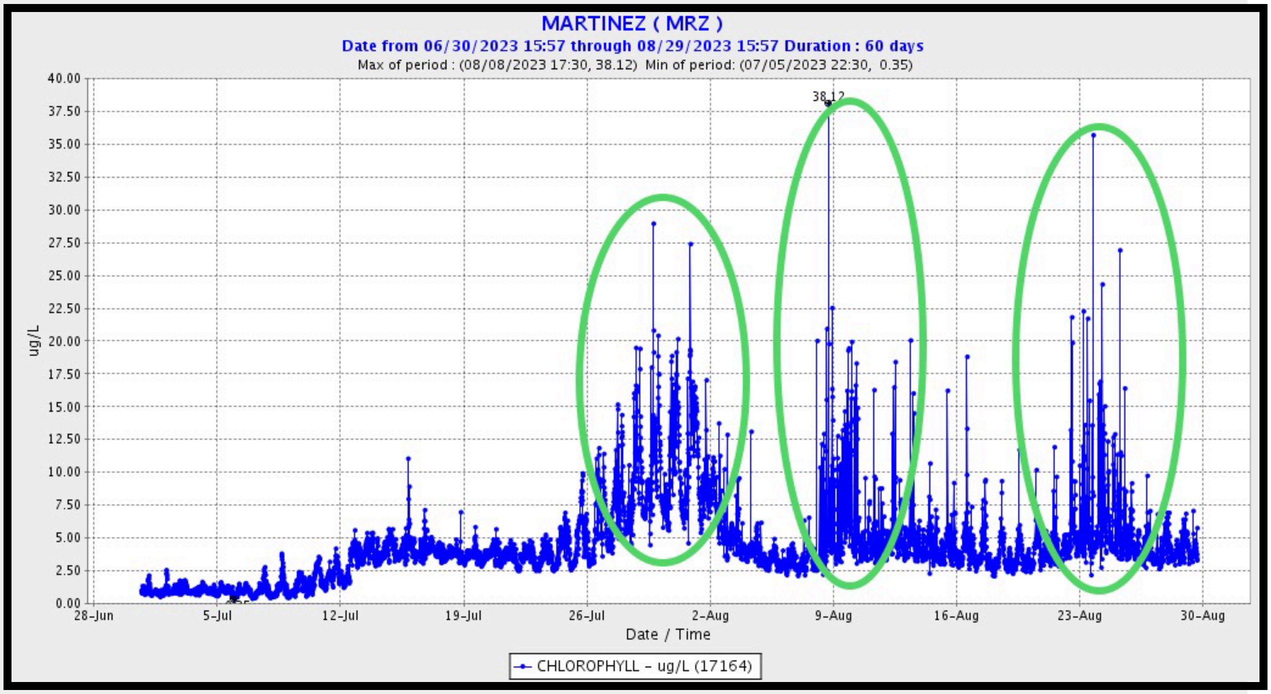

Figure 2. Chlorophyll levels at Martinez CA gage between East and North San Francisco Bay in summer 2023. Note three periods (green circles) of blooms located at this site.

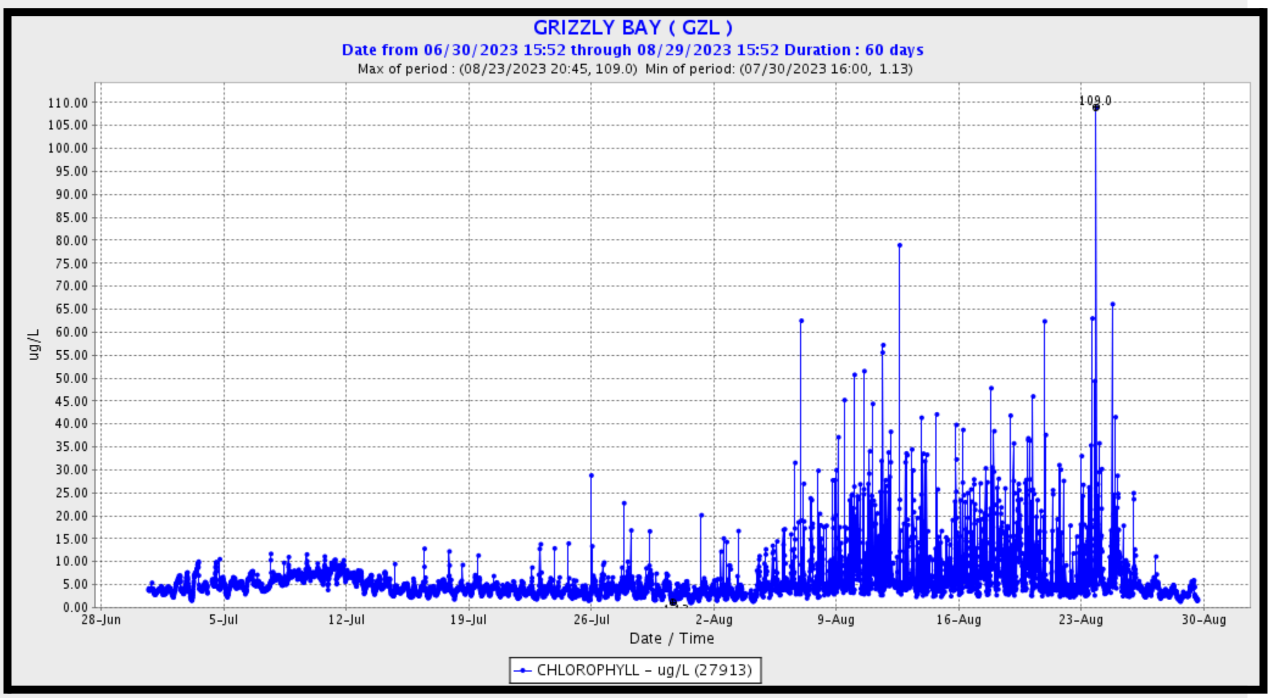

Figure 3. Chlorophyll levels at Grizzly Bay gage (in northwest East Bay) in summer 2023.

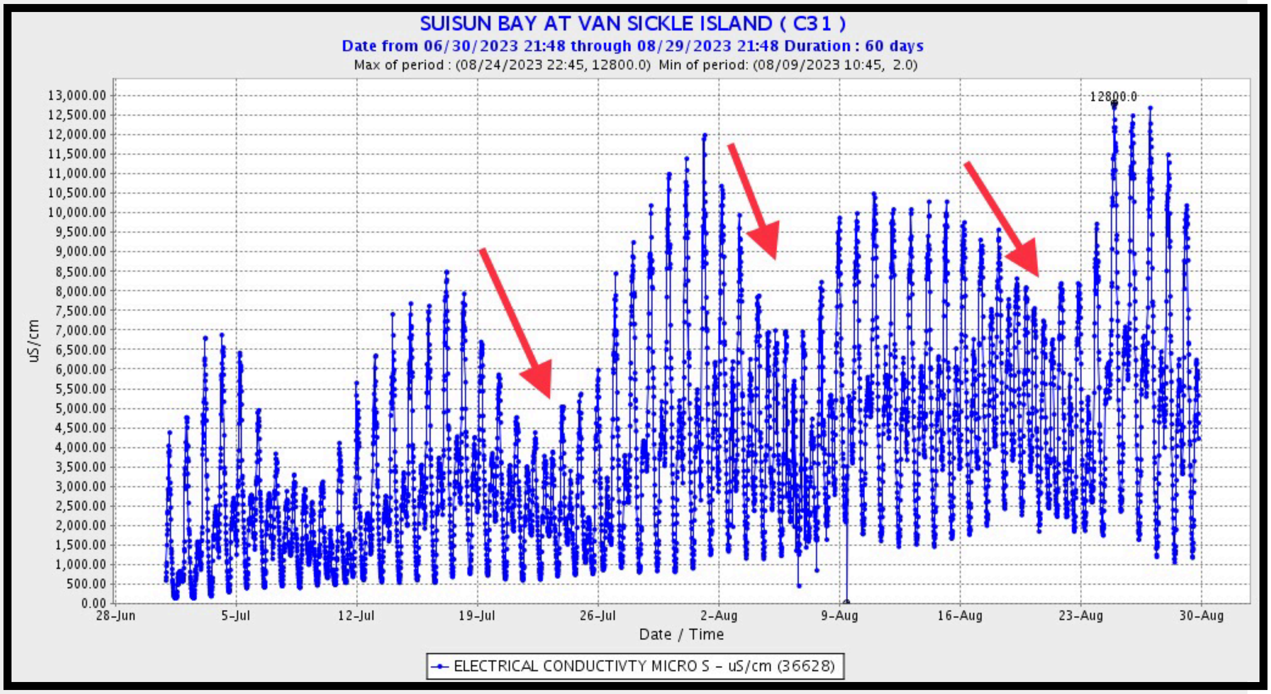

Figure 4. Salinity (EC) at eastern Suisun Bay gage (in east Bay) in summer 2023. Red arrows indicate periods of draining prior to and between full moons.

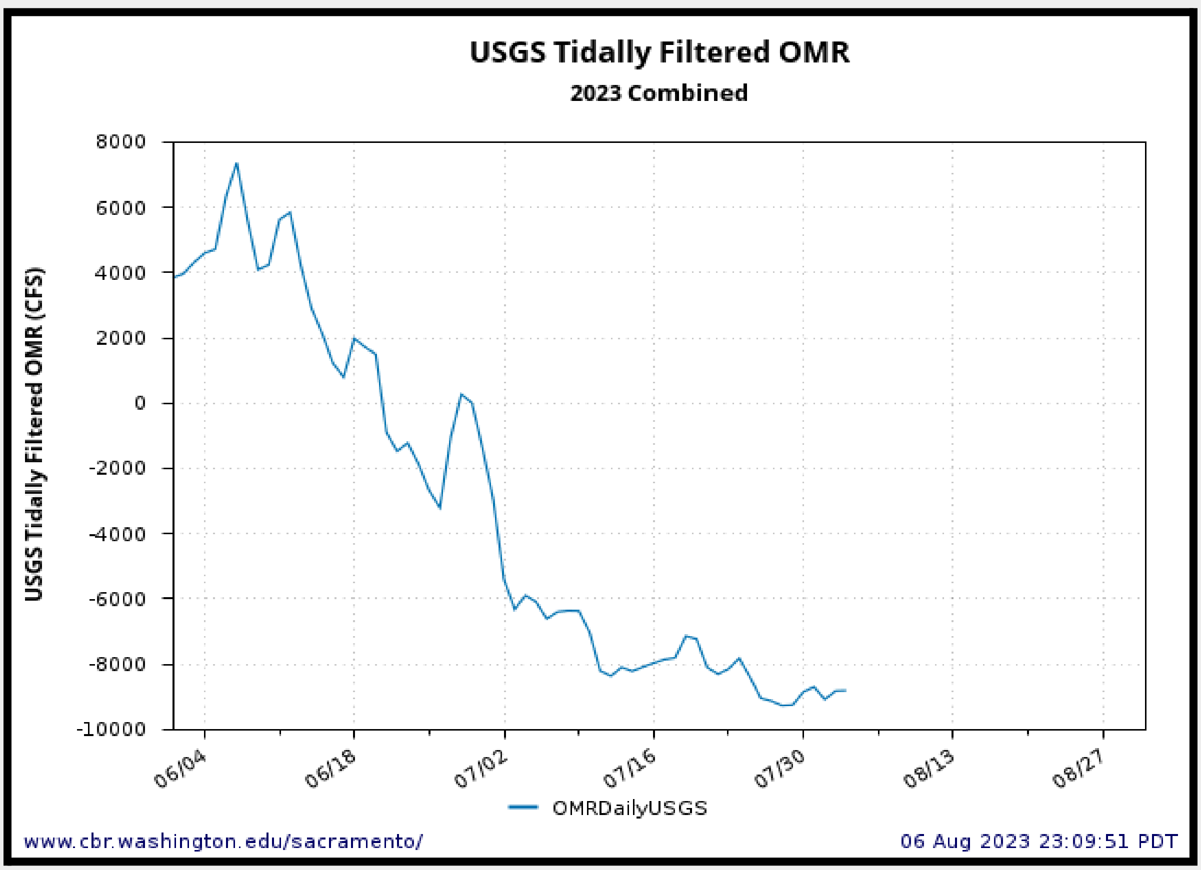

Figure 5. Daily average (tidally filtered) discharge at Pittsburg gage in Suisun Bay summer 2023. Red circles indicate drainage rates to Suisun Bay prior to two Super Moons (August 1 and 30).

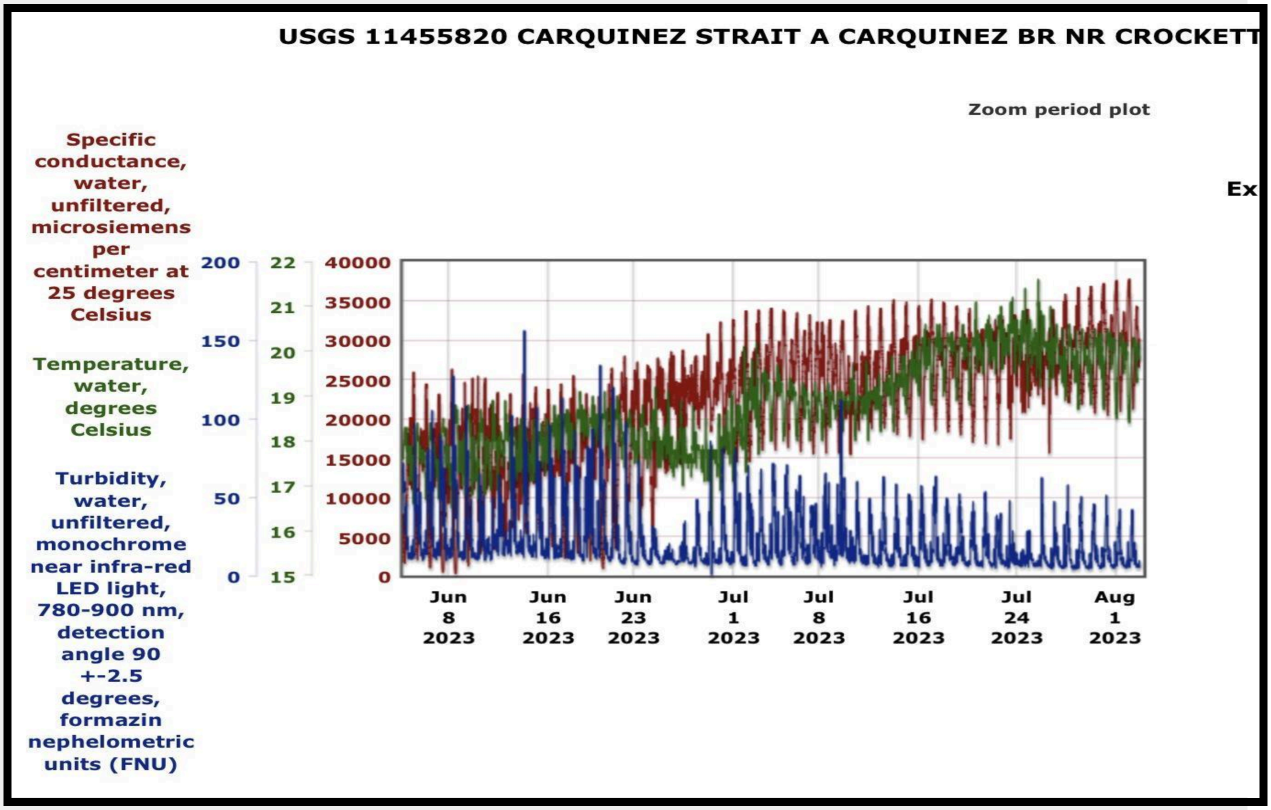

Figure 6. Hourly dissolved oxygen levels in Grizzly Bay in summer 2023. Note inverse relationship with chlorophyll levels in Figure 4. The low dissolved oxygen levels (<5 mg/l) began with the first bloom (August 1) and continued through August. Also note the Bay water quality standard is a minimum 6 mg/l dissolved oxygen level for fish health.

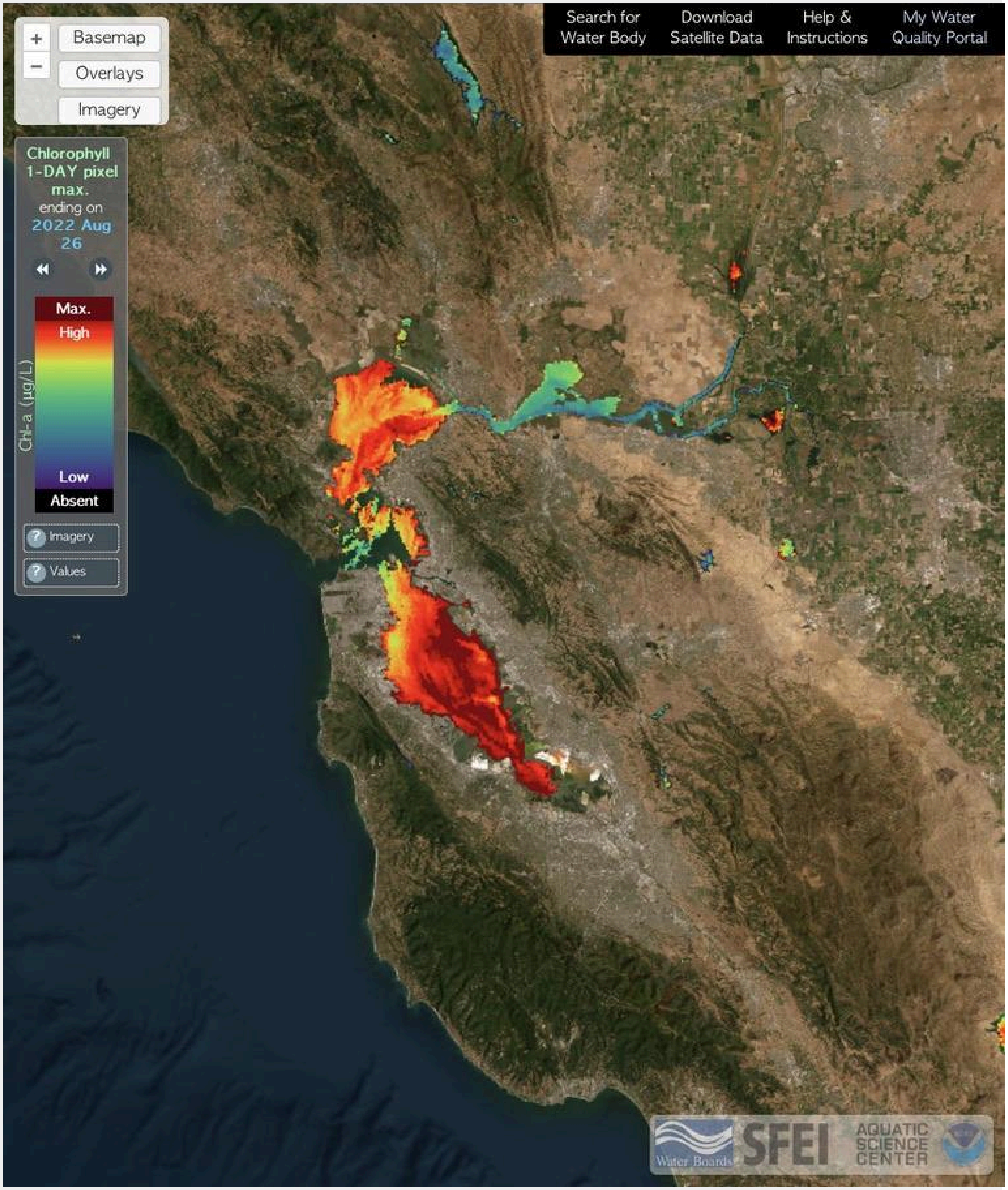

Figure 7. Satellite imagery of chlorophyll levels in San Francisco Bay on 8/29/2022. [Source]()

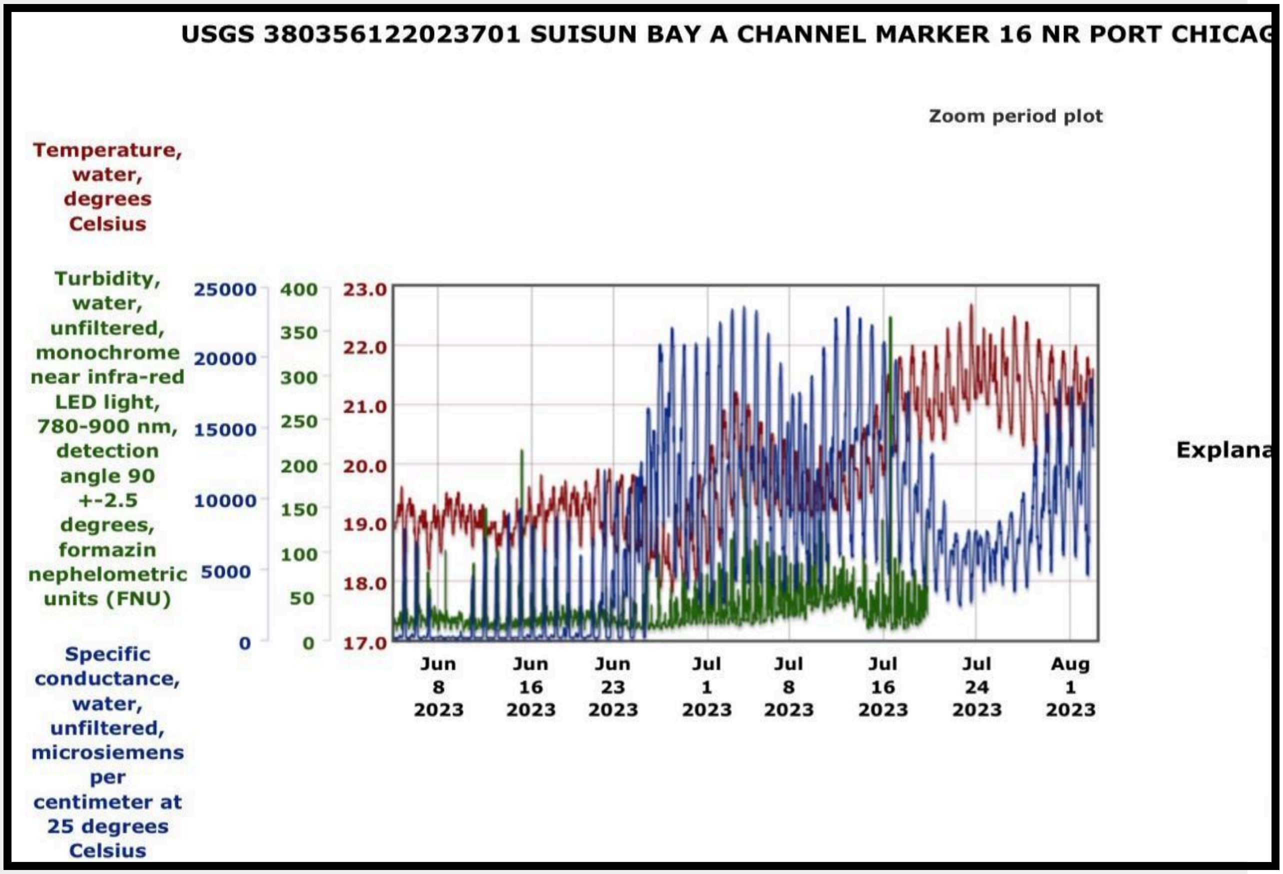

Figure 8. Water temperature, chlorophyll, and salinity in Suisun Bay in summer 2023. Note algal bloom in late August that began after the late-August draining of the Delta into the Bay when water temperatures reached 24°C (75°F).

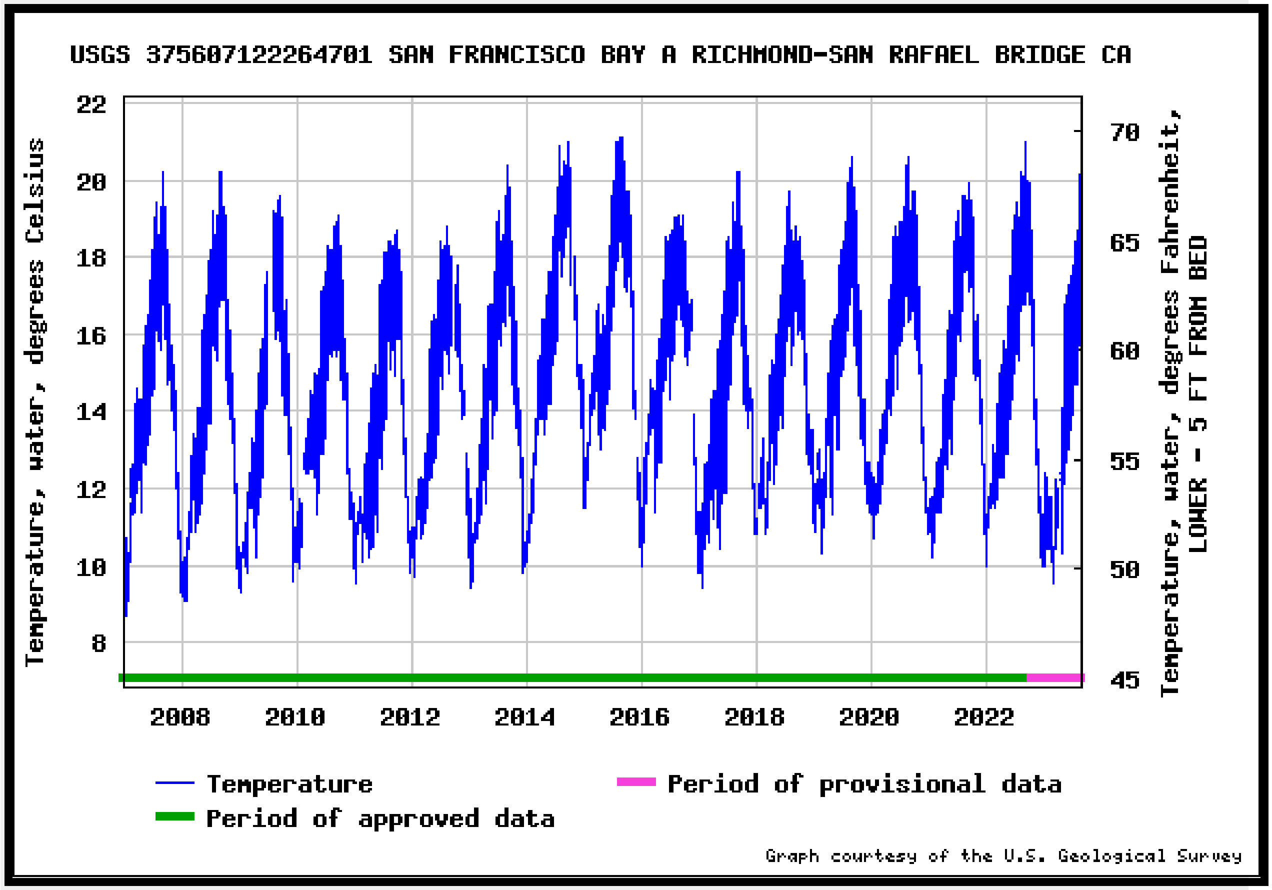

Figure 9. San Francisco Bay water temperatures from 2007-2023. Note 2023 reached 70°F (see Figure 2) a recent record reached not even reached in critical drought years 2014, 2015, and 2022.

- SWRCB (2023) – Lake Merritt Recon

This report summarizes water quality and biological observations collected by the San Francisco Bay Regional Water Quality Control Board (Water Board) and community partners in response to the mass fish kill in Lake Merritt in August 2022. The mass fish kill was associated with a harmful algal bloom (HAB) and likely caused by the subsequent dissolved oxygen (DO) depletion. The species responsible for the HAB was Heterosigma akashiwo, a type of marine species that can cause a red tide. Red tides are often attributed to oxygen depletion in the water that marine life need to survive. In addition, Heterosigma akashiwo can cause toxicity in fish leading to fish kills, although the exact mechanism is not well understood (Gómez et al., 2022). There was no evidence of toxins in water samples surrounding the HAB.

In late July 2022, observations of rusty-brown water near Alameda were reported to the Water Board's spill line. Samples collected by California Department of Public Health (CDPH) determined the cause of the discolored water was a harmful algal bloom known as a red tide. CDPH identified the species associated with this bloom as Heterosigma akashiwo. By early August, the bloom had migrated into Lake Merritt, and by late August it had expanded throughout most of the San Francisco Bay. Fish deaths around the San Francisco Bay were being reported as early as August 22. However, the most obvious fish deaths in Lake Merritt did not occur until August 28.

Dissolve oxygen (DO) levels were likely a main contributor of fish mortality, indicated by DO levels near 0 mg/L during and following the fish kill in Lake Merritt. The Basin Plan designates 5 mg/L of DO as the water quality objective for saline, marine, and warm fresh waters. DO levels below 2 mg/L are considered hypoxic and unable to support aquatic life. Data from the continuous monitoring device at the boat dock showed DO near 0 mg/L on August 29.

Comment: Note similar conditions throughout the Bay in 2022 (see Figures 9-12 earlier in this chapter).

J. Supplemental data from USGS and CDEC - River, Delta, and Bay Water Temperatures, Salinity, Chlorophyll, and Flow Rates related to Bay Algae Blooms in 2022 and 2023 with annotations.

The following are additional data presentations on the summer Bay algae blooms in 2022 and 2023. The main theme herein is that the blooms were the consequence of high Bay water temperatures brought on by warm waters draining from the East Bay and Delta in strong neap tide periods before full moons. Anticipation of such events by providing higher river flow and Delta inflow/outflow may reduce Bay water temperatures and limit the extent and effects of the blooms. The data also support our recommendations for summer streamflows and water temperatures in the lower Sacramento River and its lower tributaries upstream of the Delta in support of minimizing algae blooms in the Bay.

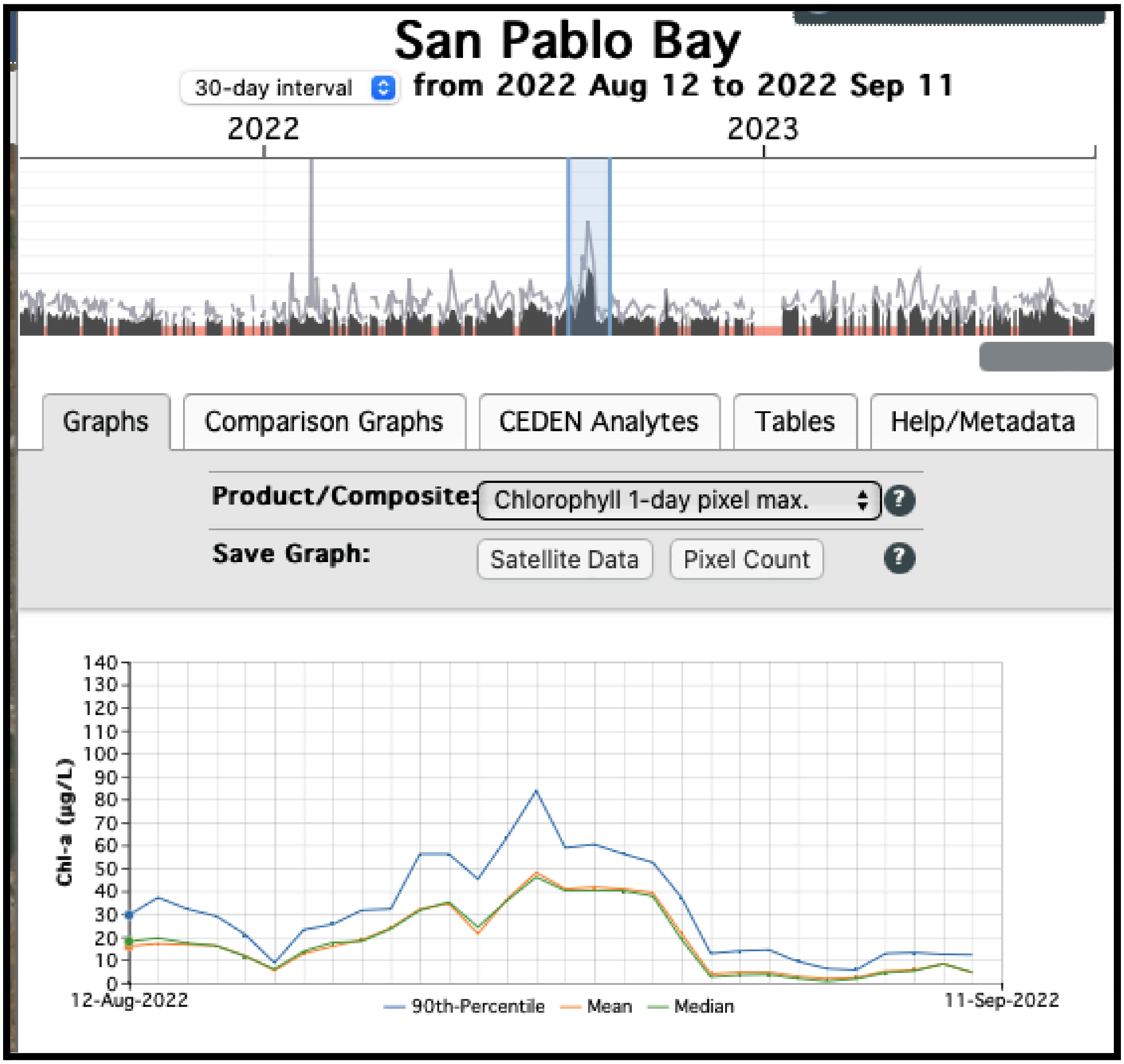

Figure J-1. Chlorophyll data from San Pablo Bay in 2022-2023. Data are shown by day during the late August 2022 bloom. Source

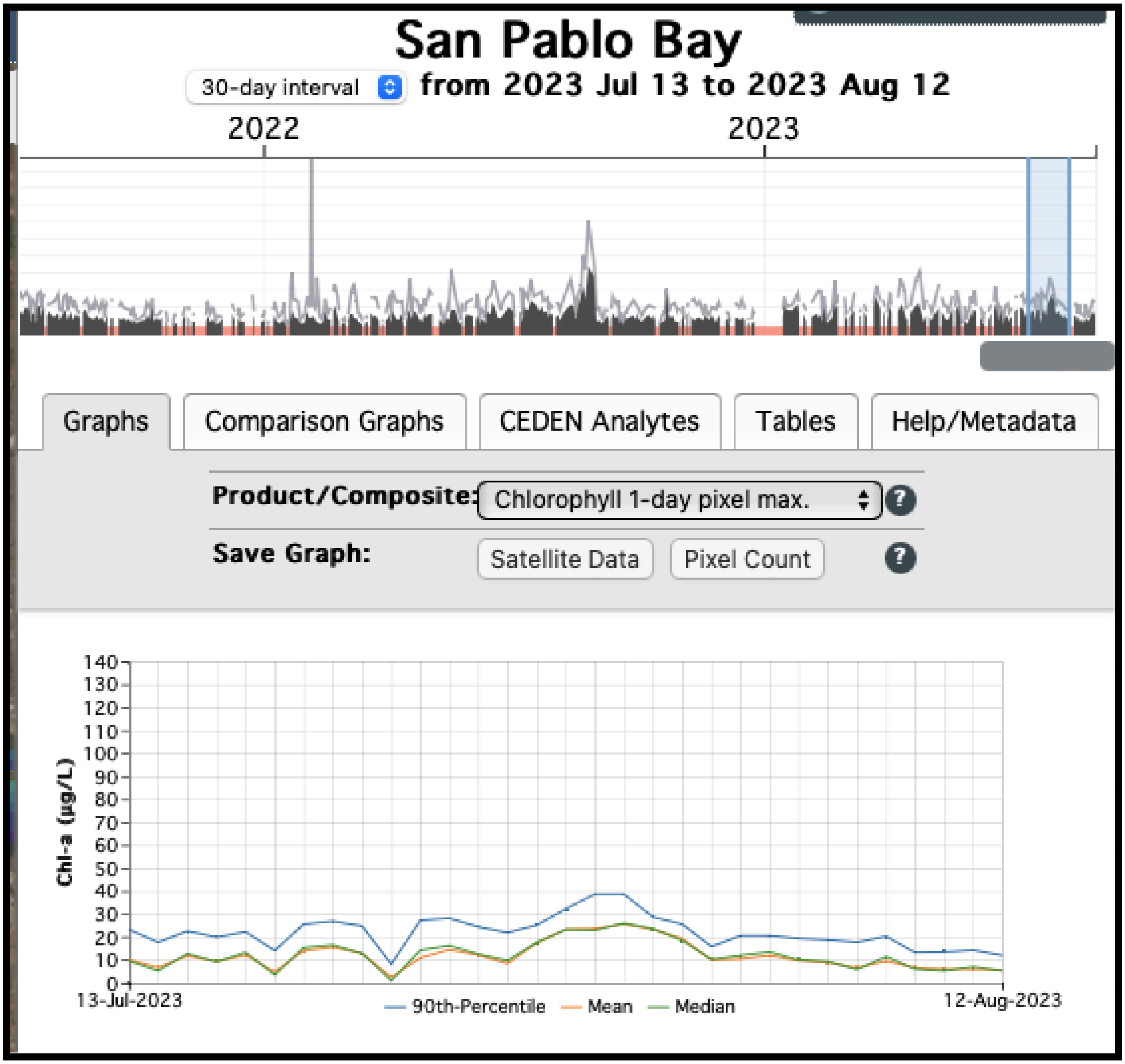

Figure J-2. Chlorophyll data from San Pablo Bay in 2022-2023. Data are shown by day around the late July 2023 bloom. [Source]

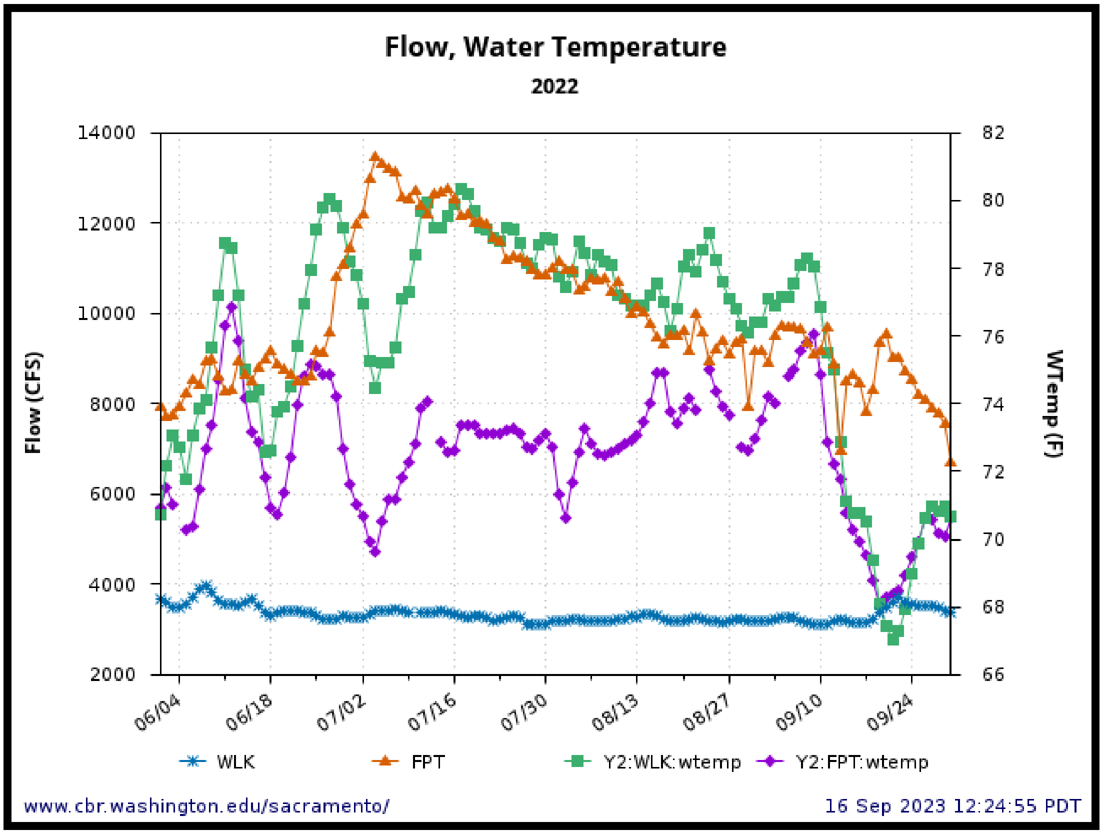

Figure J-3. Water temperatures and streamflow in the lower Sacramento River below Wilkins Slough (rm 120) and at Freeport at the entrance to the Delta in summer of drought year 2022. The extremely warm water temperatures contributed to high Delta and Bay water temperatures that in turn contributed to the August bloom in the Bay. It takes streamflows of 6000-10,000 cfs at Wilkins Slough and 16.000-20,000 cfs at Freeport (WLK+GRL+AWB) to achieve 68ºF target water temperatures in summer.

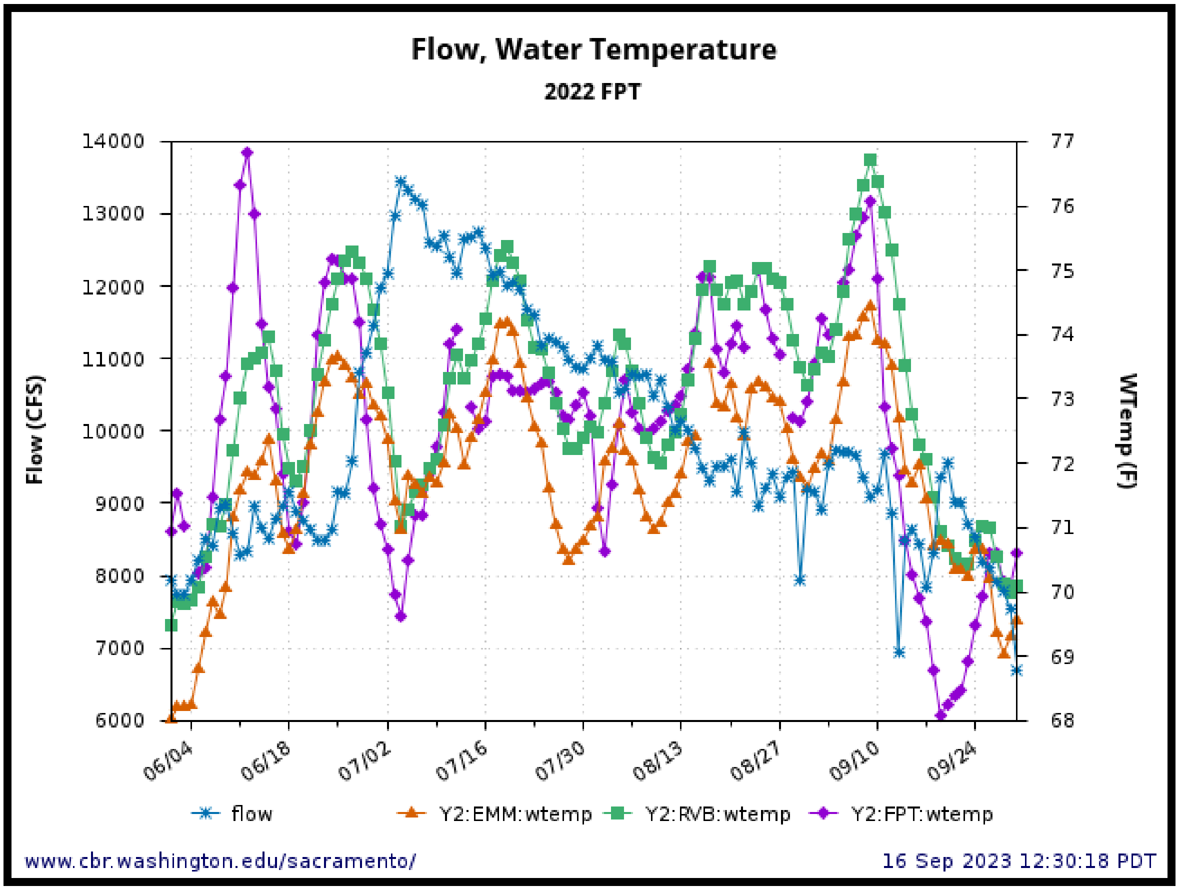

Figure J-4. Streamflow and water temperatures in the lower Sacramento River at Freeport at the entrance to the Delta and the exist of the Delta at Rio Vista and Emmaton in summer 2022. The extremely warm water temperatures in the Delta (Freeport and Rio Vista) and entrance to the Bay (EMM) in turn contributed to the late August bloom in the Bay. Note that during periods of high streamflow (inflow), 7/1-7/5, water temperatures dropped sharply. The period of low streamflow in mid and late August lead to high (75F) water temperatures.

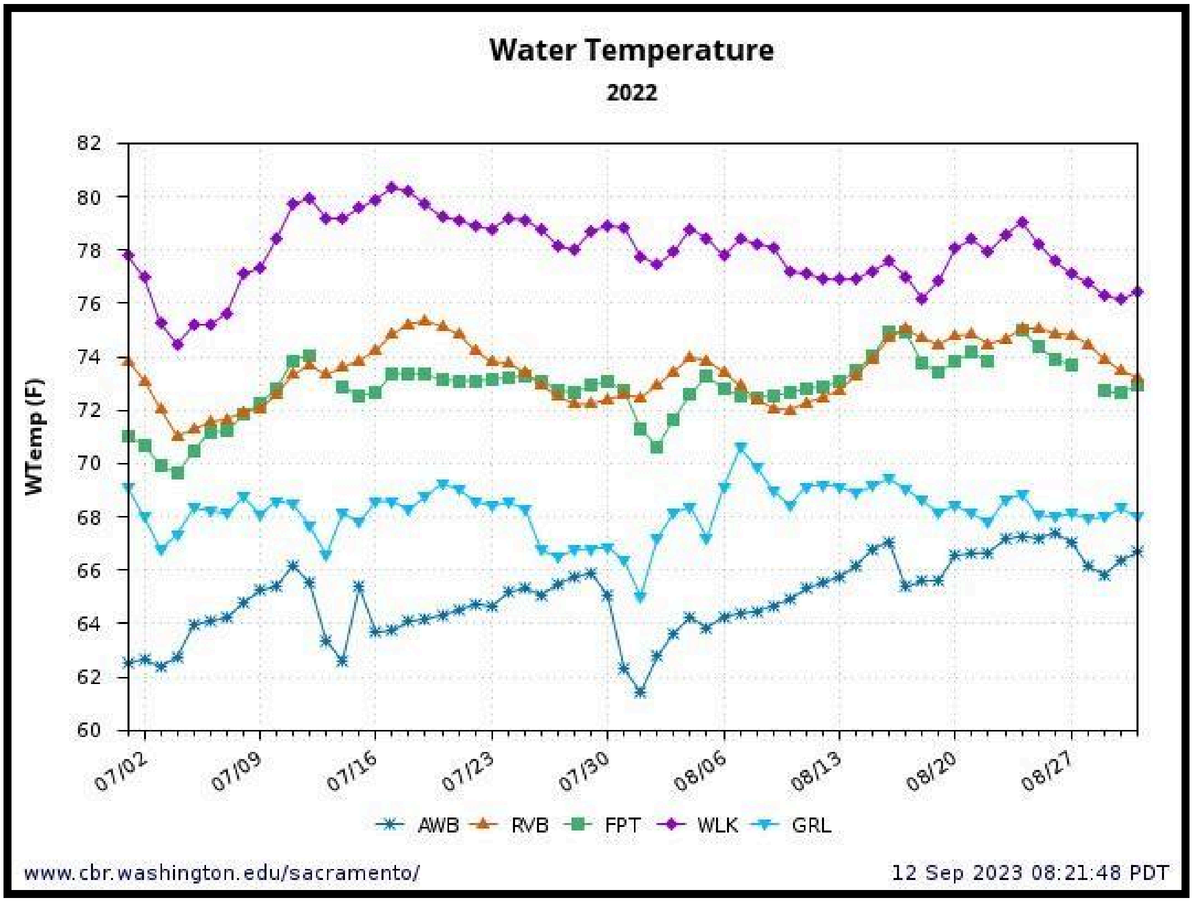

Figure J-5. High water temperatures (75ºF) at Freeport and Rio Vista in the Delta were the result of warm water temperatures in the lower Sacramento upstream of the lower Feather (GRL) and lower American River (AWB). We recommend maintaining the lower Sacramento River temperature at Wilkins Slough at or below 68º F and the lower Feather at Gridley (GRL) and American Rivers at Watt Bridge (AWB) at 65ºF to provide the target 68º F at Freeport at the entrance to the Delta and 72º F through the north Delta to the Bay.

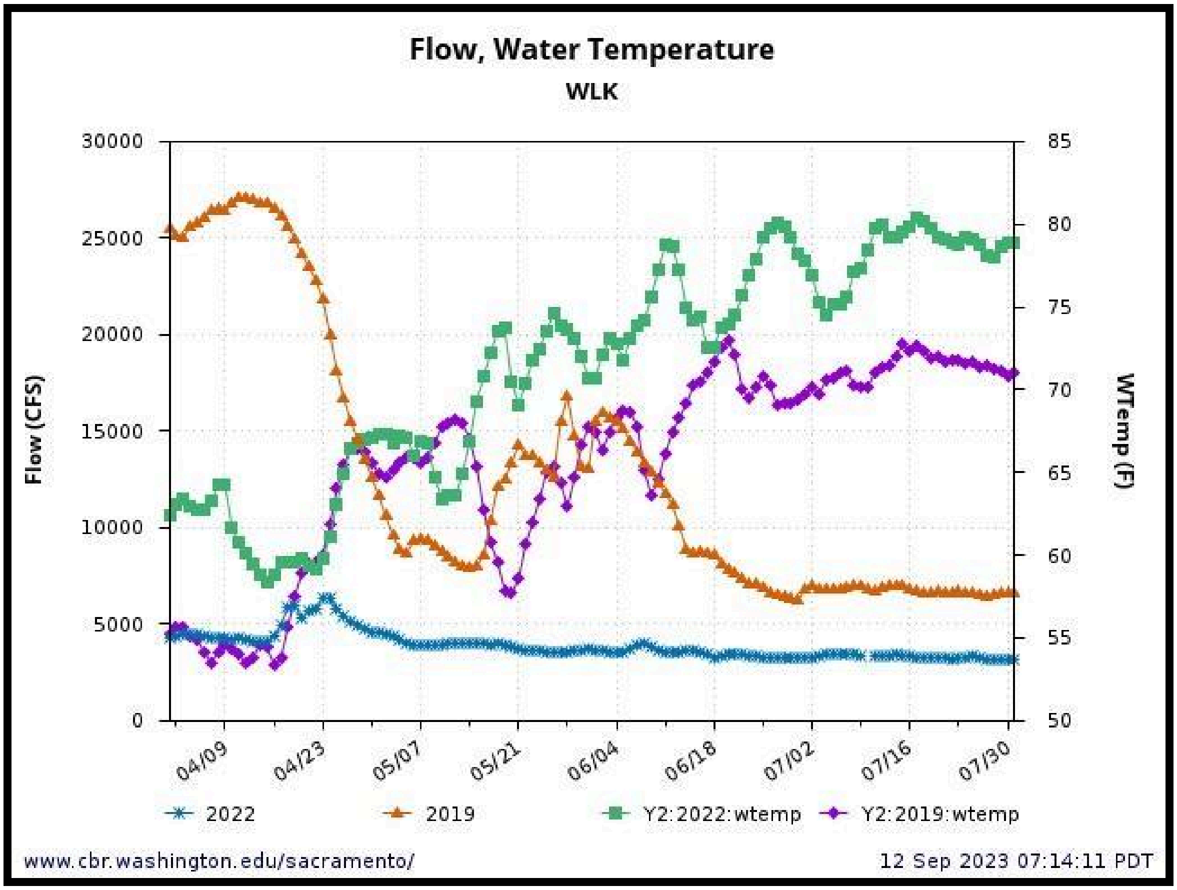

Figure J-6. High water temperatures (>75ºF) in spring and early summer in the lower Sacramento River at Wilkins Slough in critical drought year 2022 were the result of low Sacramento River streamflow (<5,000 cfs) when compared to wet year 2019. Pulses of streamflow in late May and June led to reduced water temperatures.

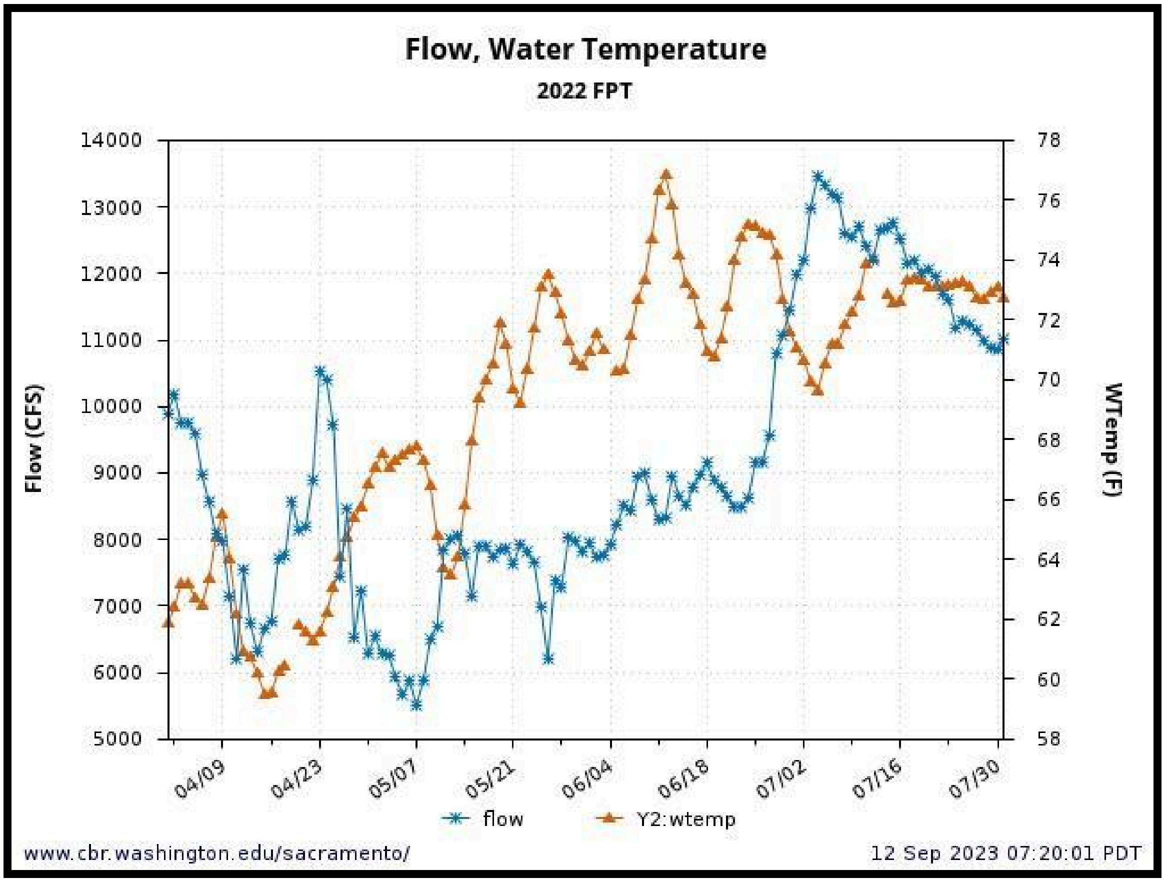

Figure J-7. High water temperatures (75ºF) in spring and early summer in the lower Sacramento River at Freeport at the entrance to the Delta were the result of low Sacramento River streamflow (<10,000 cfs) in addition to high water temperatures upstream in the lower Sacramento River at Wilkings Slough. Note the pulse flow in early July led to a 5C reduction in water temperature.

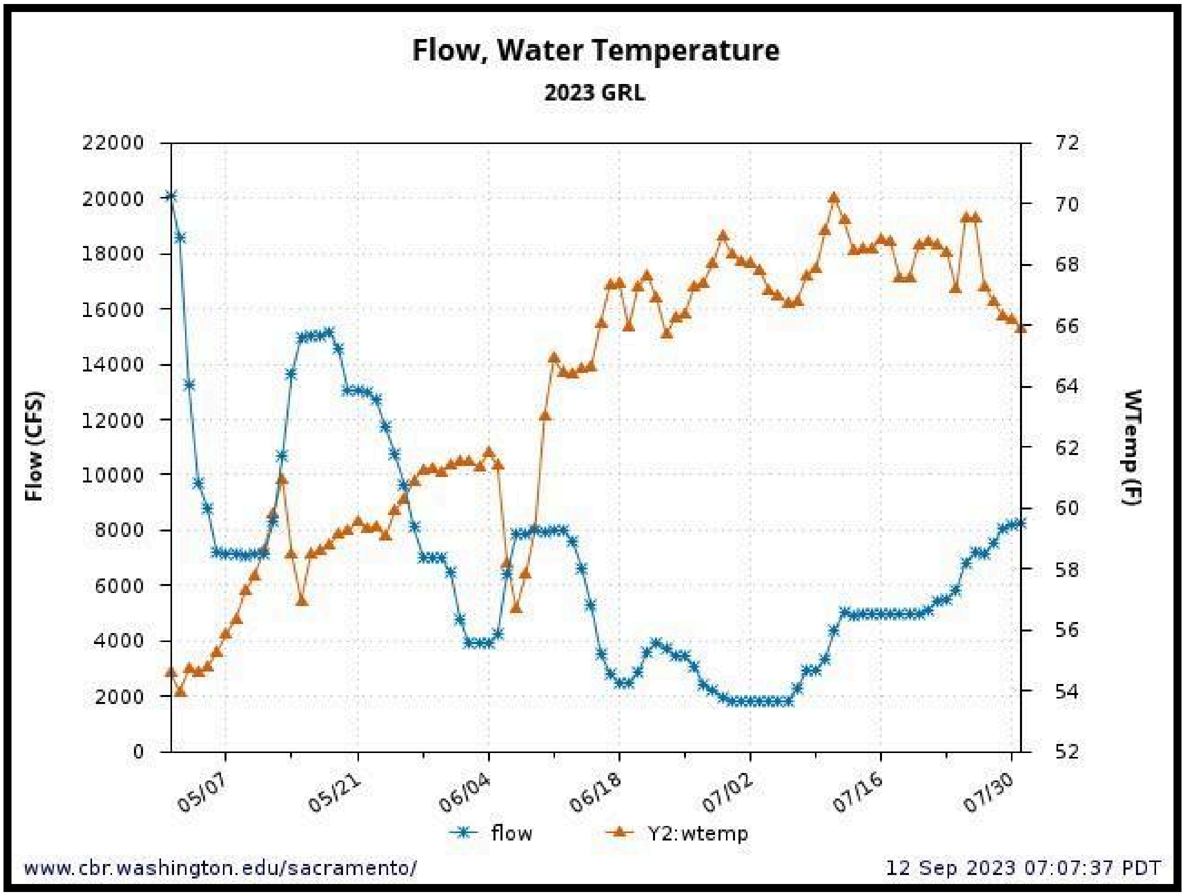

Figure J-8. Streamflow and water temperature in the lower Feather River at Gridley (GRL) in wet year 2023. We recommend water temperatures at GRL remain below 60ºF through May and 65ºF June-Sept with streamflows of 6,000-8,000 cfs to support our recommended water temperatures in the lower Sacramento River at Freeport of 65ºF through May and 68ºF from June-Sept.

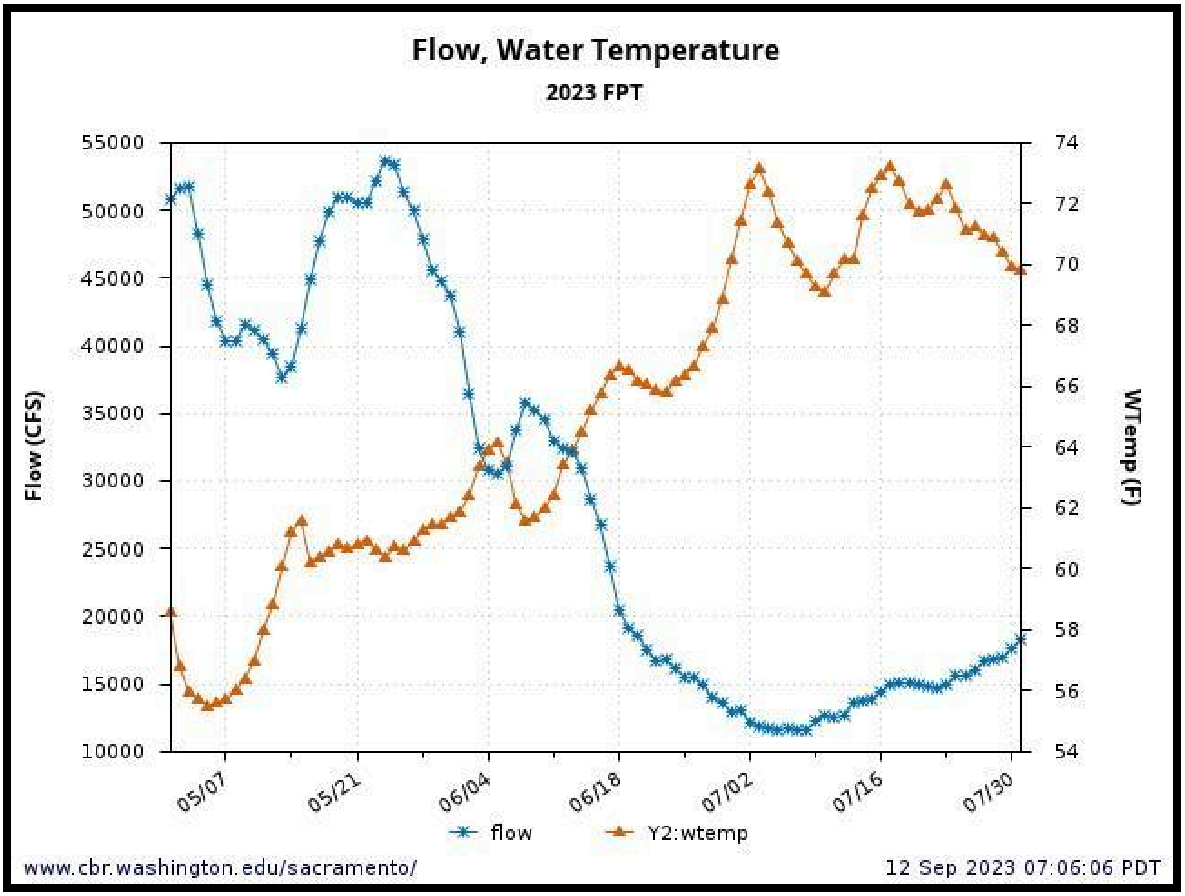

Figure J-8. Streamflow and water temperature in the lower Sacramento River at Freeport at the entrance to the Delta in wet year 2023. We recommend water temperatures at FPT remain below 65ºF through May and 68ºF June-Sept. It will take streamflows at Freeport of 16,000-20,000 cfs to achieve 65ºF through May and 68ºF June-Sept.

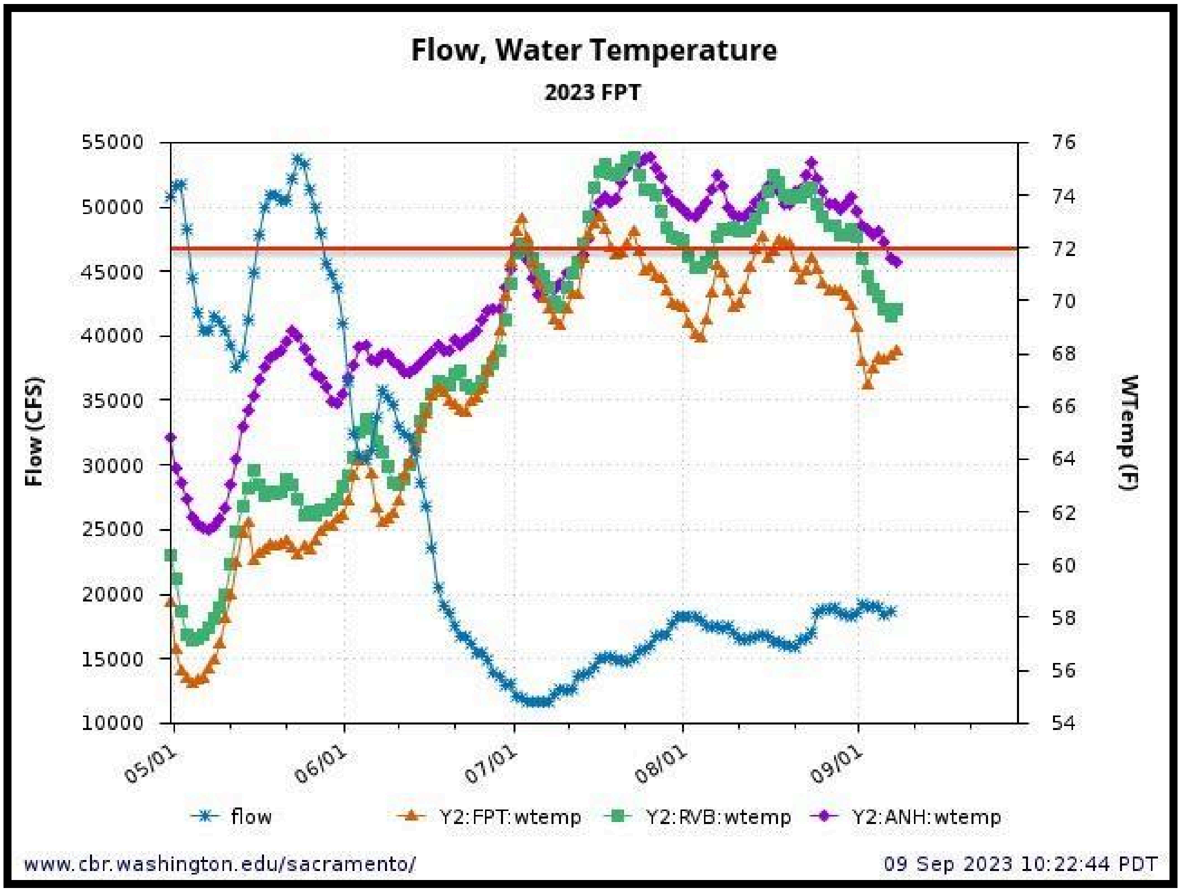

Figure J-9. Streamflow and water temperature at Freeport in the lower Sacramento River at the entrance to the Delta in wet year 2023. Also shown are water temperatures at Antioch (ANH) on the San Joaquin River and Rio Vista Bridge (RVB) on the Sacramento River as these channels leave the Delta near the entrances to the Bay where our recommended summer maximum water temperature is 72ºF (red line). It will take streamflows at Freeport of 16,000-20,000 cfs to achieve our recommended 72ºF through the summer.

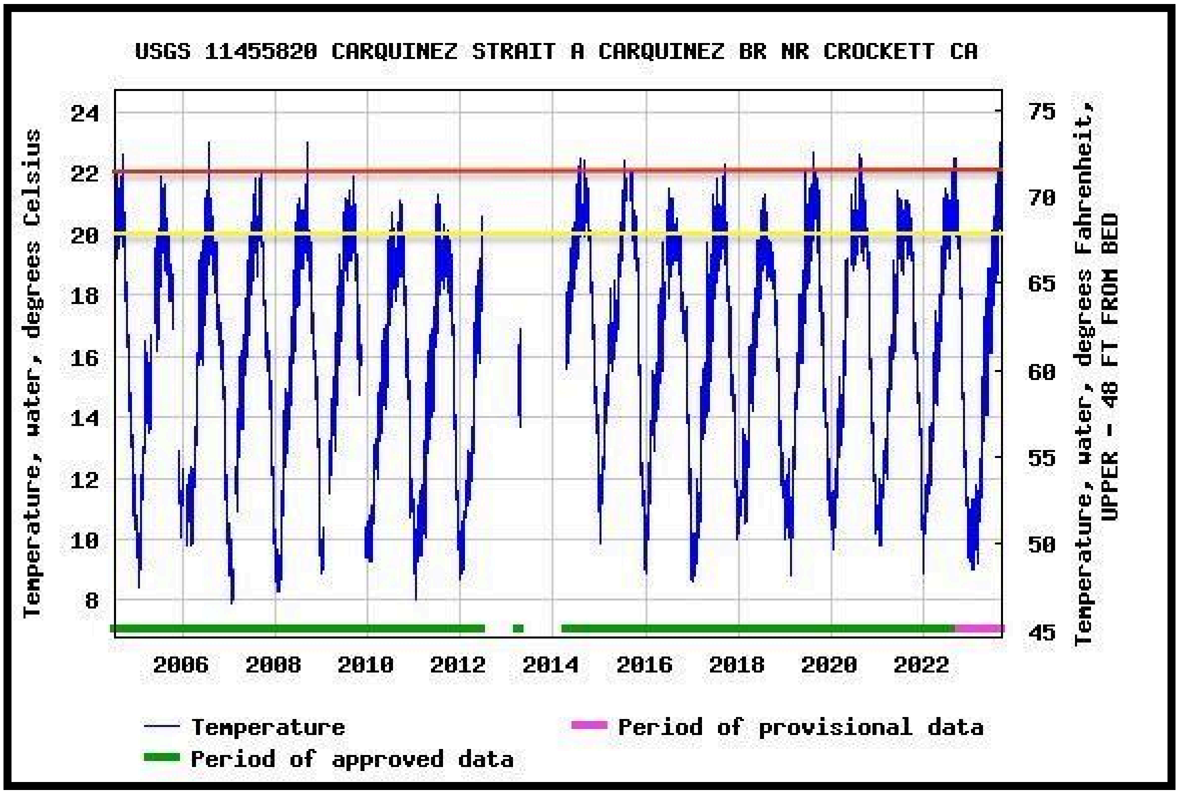

Figure J-10. Water temperature at Crockett in the Carquinez Straight between the North Bay and Suisun Bay 2005-2023. The red line shows highly stressful water temperatures (>22C/72F) for sturgeon in summer with summer exceedances in most drought years (07, 08, 14, 15, 22) but also in many wet years (06, 17, 19, 23). The yellow line is the upper safe level for sturgeon (20C/68F). Our recommendation is to not exceed 70ºF at the Carquinez Bridge and in San Pablo Bay to minimize the potential for harmful algae blooms and provide safe water temperature for this prime sturgeon summer habitat.

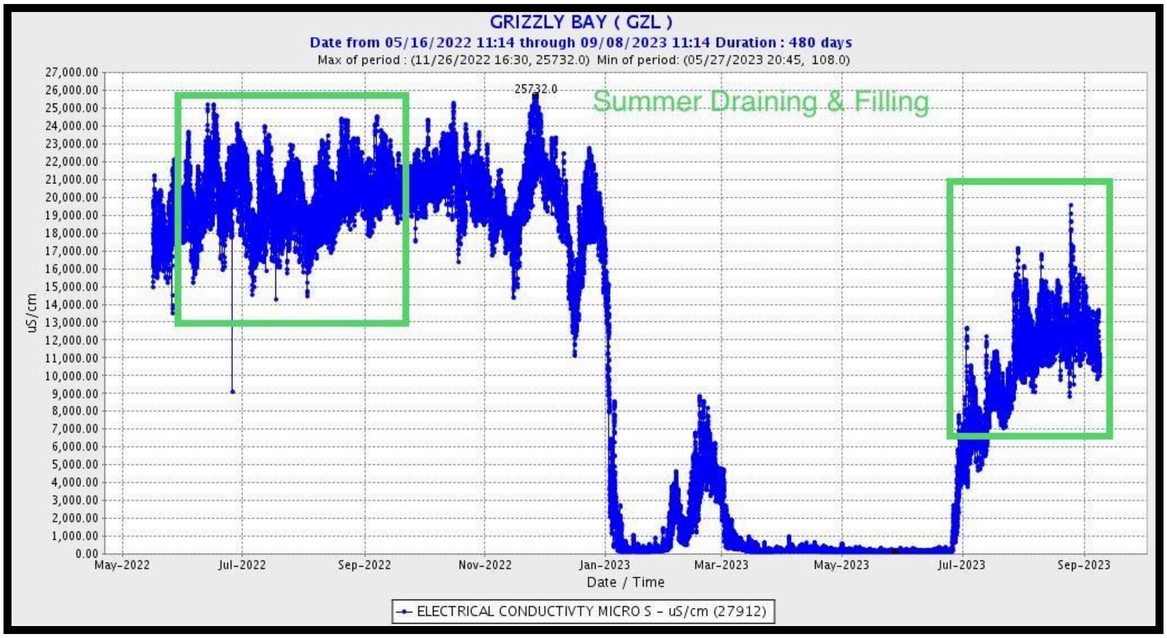

Figure J-11. Salinity (EC) in Grizzly Bay (west Suisun Bay) in 2022 and 2023 showing periods of draining and filling with the tidal cycles that contributed warming from the draining of Suisun Marsh and the west Delta into Suisun Bay.

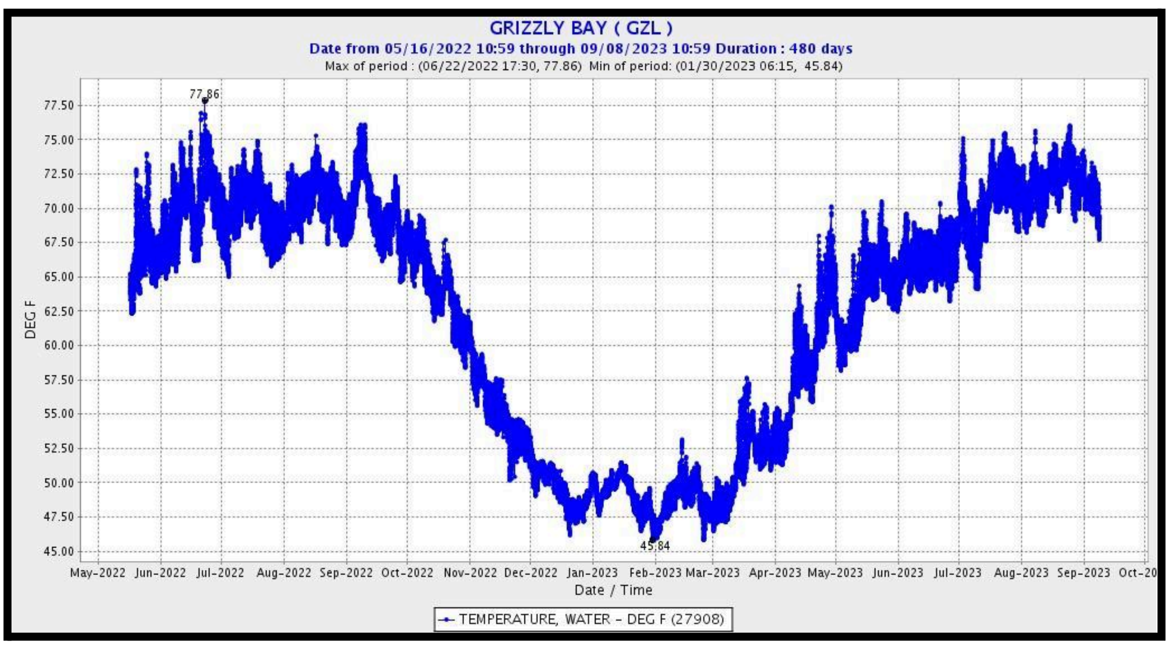

Figure J-12. Water temperature in Grizzly Bay (west Suisun Bay) in 2022 and 2023 showing periods of draining and filling with the tidal cycles that contributed warming from the draining of Suisun Marsh and the west Delta into Suisun Bay. Our recommended maximum water temperature for Suisun Bay in summer is 72ºF.

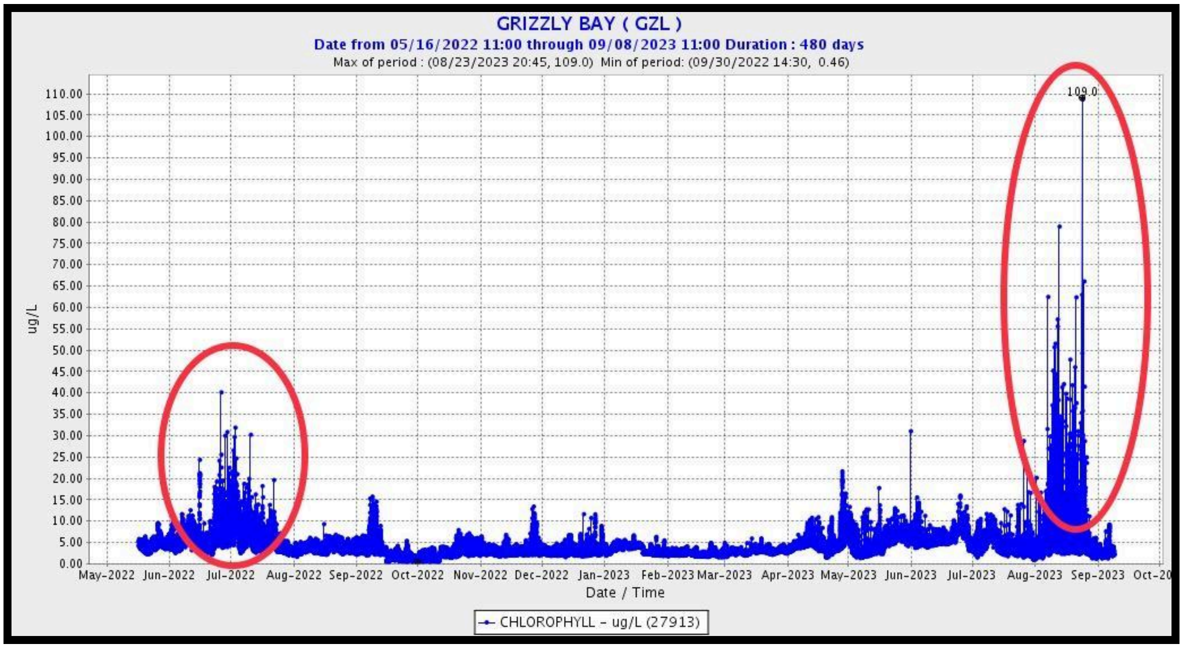

Figure J-13. Algal blooms (chlorophyll) in Suisun Bay in summer 2022 and 2023.

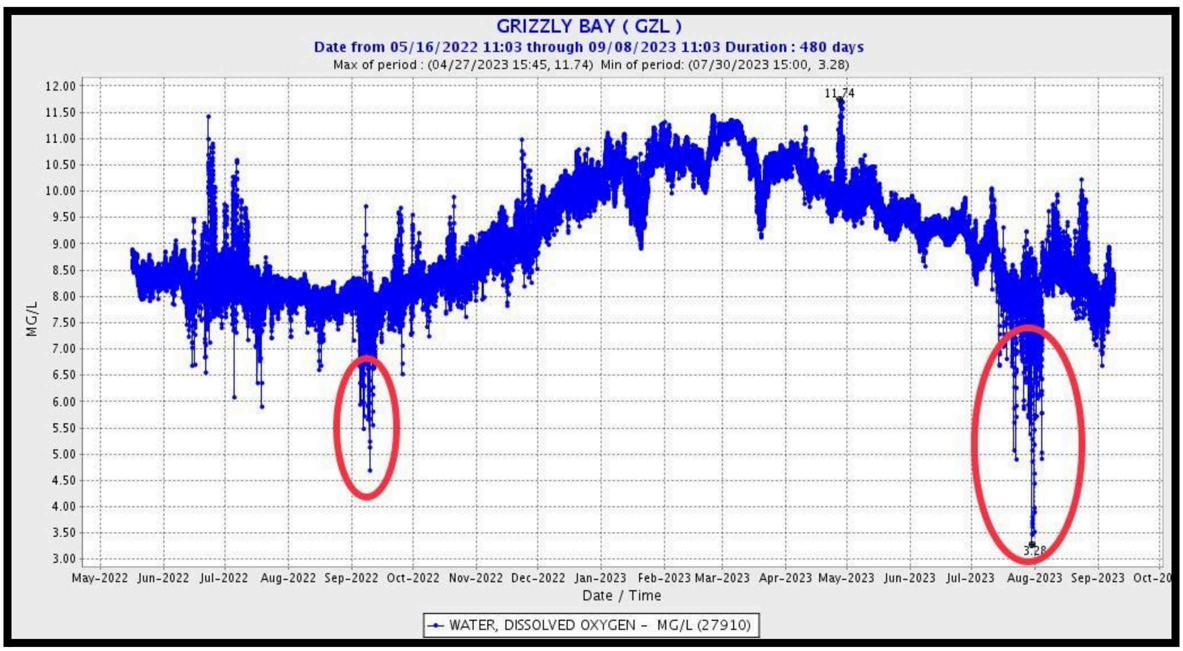

Figure J-14. Dissolved oxygen (MG/L) in Suisun Bay in summer 2022 and 2023. Red circles denote low DO periods associated with algae blooms. Water quality standard for Bay is >5 MG/L.

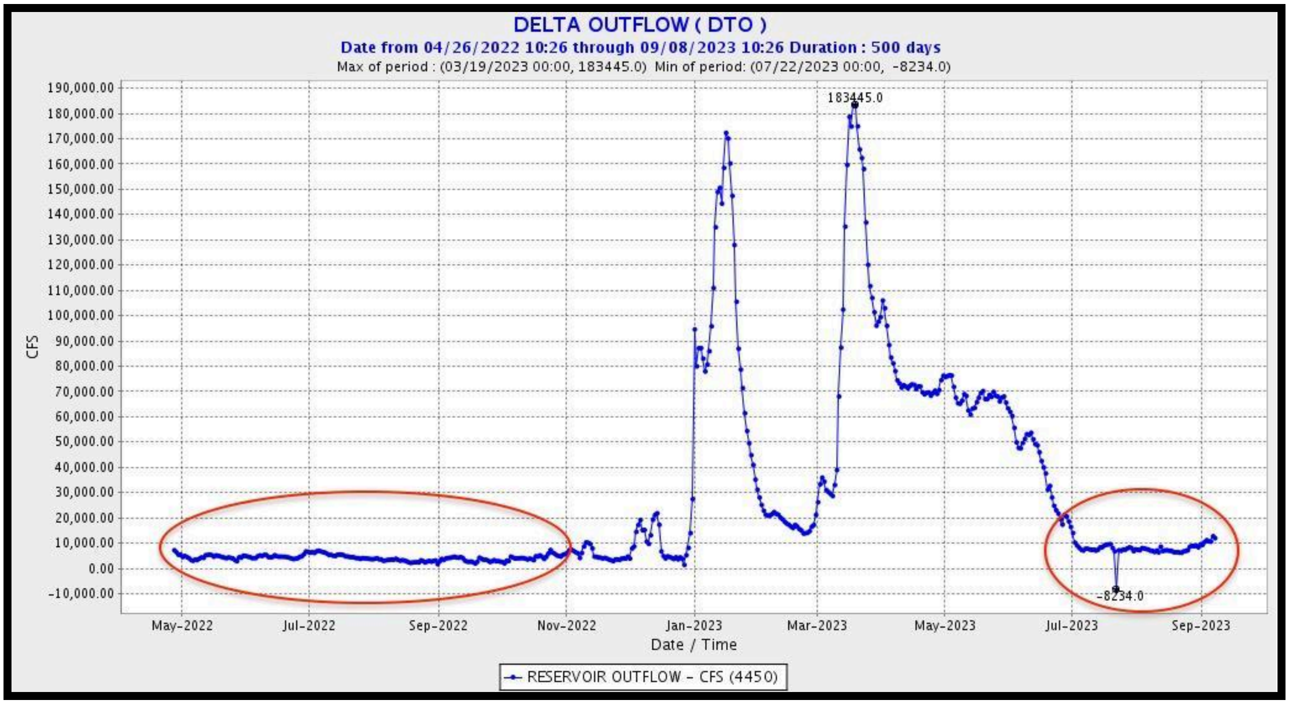

Figure J-15. Warm water and plankton blooms in the Bay are associated with low Delta outflow (<10,000 cfs) in the summer of dry and wet years as seen for 2022 and 2023. We recommend a minimum Delta outflow of 8,000 cfs in dry years and 12,000 cfs in normal and wet years.

K. USFWS Chipps Island Trawl Survey Data Review[4]

The USFWS has conducted monthly midwater trawl surveys at Chipps Island in Suisun Bay since 1976. Sturgeon though rarely captured in the midwater trawls, were sometimes captured. Of particular note was an order of magnitude higher catch in the two decades before 2000 compared to the two decades after 2000.

- Catch statistics on 530 white sturgeon collected 1976-2001.

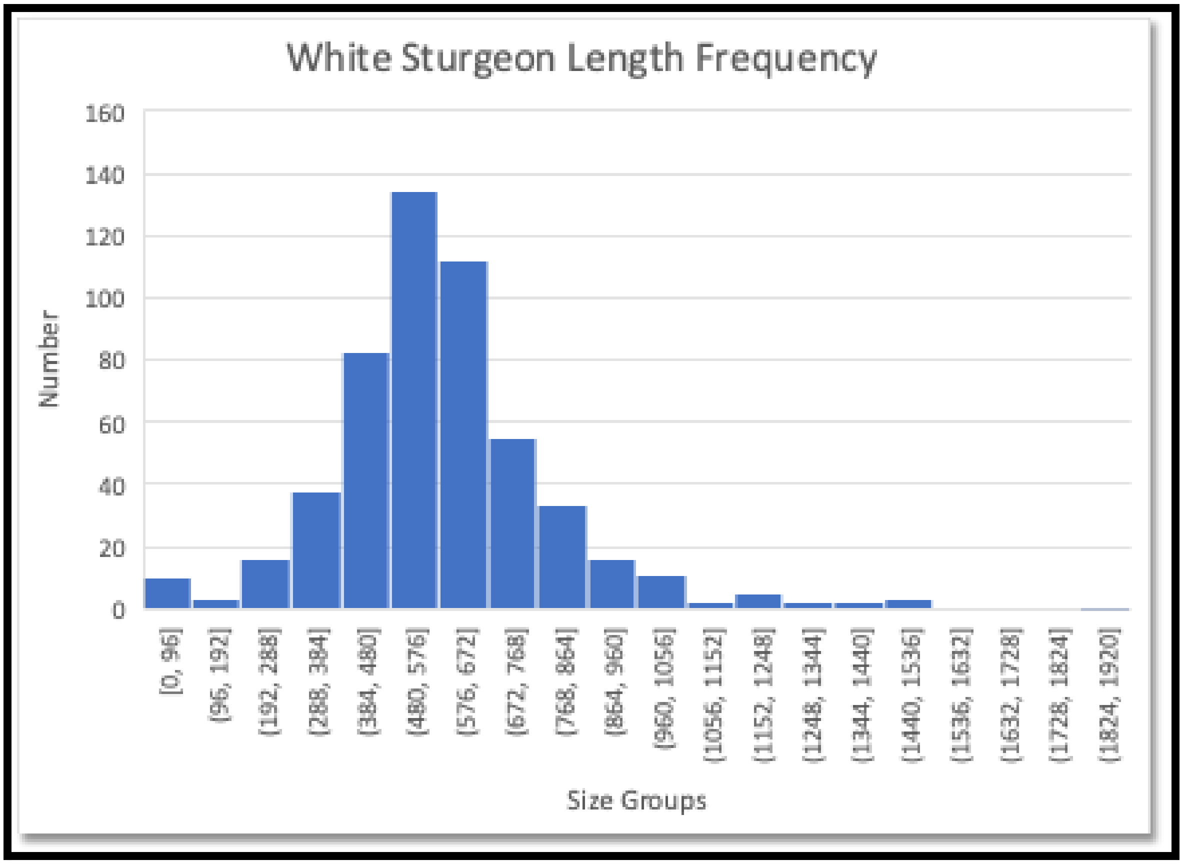

Figure 1. White sturgeon catch length-frequency chart 1976-2001 (530 white sturgeon caught).

[4] Data Source: https://portal.edirepository.org/nis/mapbrowse?packageid=edi.244.4, https://portal.edirepository.org/nis/dataviewer?packageid=edi.244.4&entityid=71c16ead9b8ffa4da7a52da180f601f4

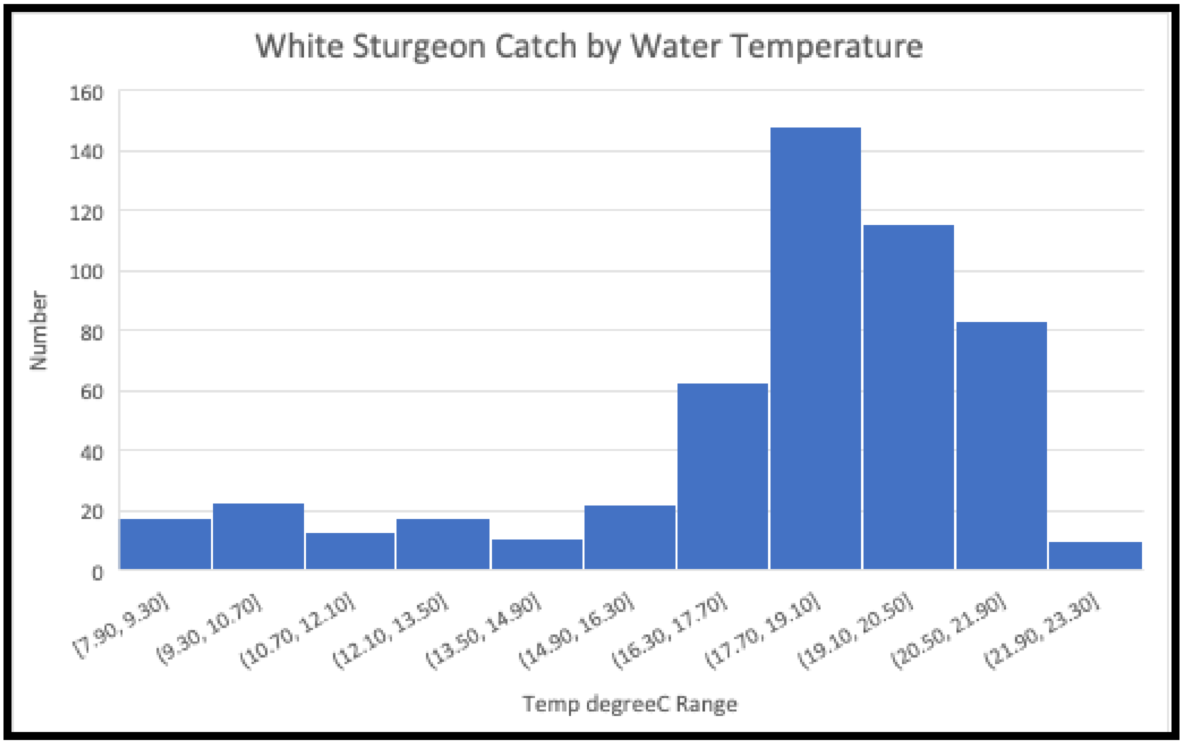

Figure 2. White sturgeon catch by water temperature (C) at collection.

- Catch statistics on green sturgeon (1976-2001).

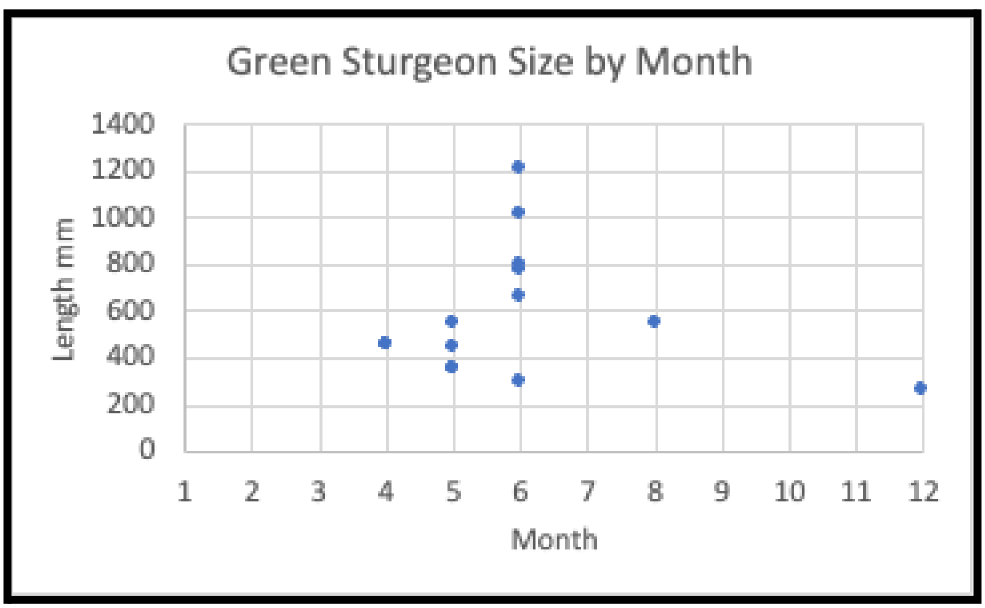

Figure 3. Green sturgeon catch by month and size group (2002-2019).

- Catch statistics for white sturgeon (2002-2019)

A total of 39 white sturgeon were collected in Chipps Island Trawl Survey from 2002 to 2019. Most were collected in spring months (Figure 5). Only one was collected in water temperature above 20ºC/68ºF (Figure 6). Only 3 green sturgeon were caught in survey years 2002-2019.

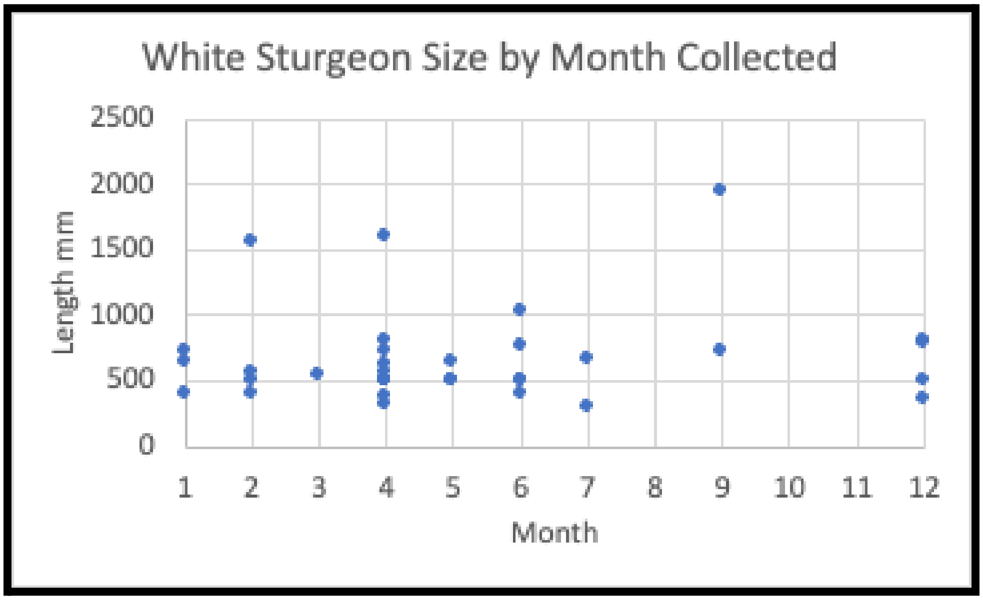

Figure 5. White sturgeon catch by month (2002-2019).

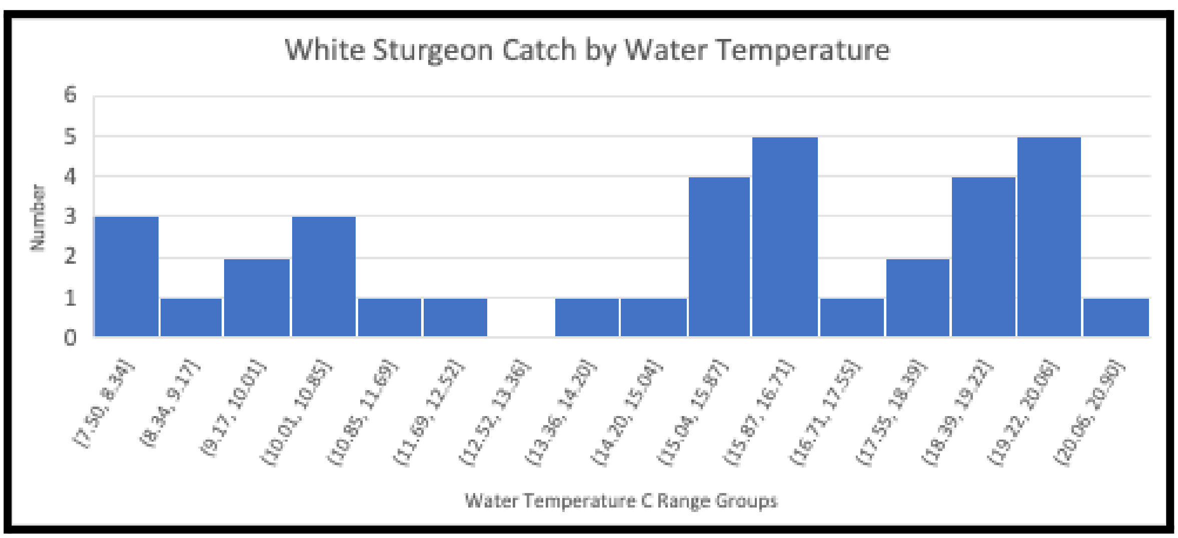

Figure 6. White sturgeon catch by water temperature (C) at collection. All catches were at 20C/68F or below. (July catches in Figure 5 were 67 and 69ºF)