Long-Term Operation – Biological Assessment

Chapter 8 – Green Sturgeon

Central Valley Project, California

Interior Region 10 – California-Great Basin

U.S. Department of the Interior

November 2023

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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The southern distinct population segment of North American green sturgeon (*Acipenser medirostris*) (green sturgeon) and designated critical habitat occurs in the action area and may be affected by the Proposed Action. Green sturgeon is an anadromous fish species that can live 60 to 70 years and grow to a size of 6.5 feet. Green sturgeon spawn in the Sacramento River and spend most of their life in the nearshore marine environment and coastal bays and estuaries along the west coast of North America.

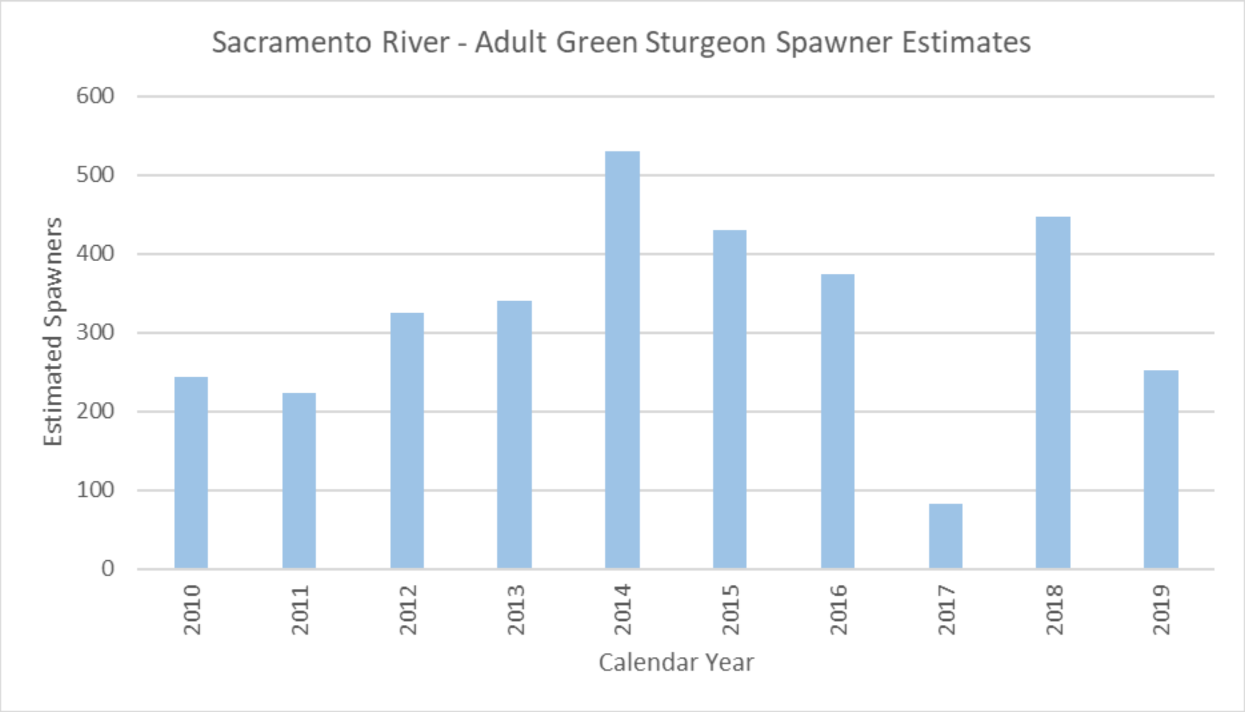
8.1 Status of Species/Critical Habitat

The National Marine Fisheries Service (NMFS) listed green sturgeon as threatened on April 7, 2006 (71 *Federal Register* [FR] 17757), and designated critical habitat on October 9, 2009 (74 FR 52300).

8.1.1 Distribution and Abundance

The historical spawning range of southern distinct population segment (sDPS) green sturgeon is not well known, though they are thought to have spawned in many of the major tributaries of the Sacramento River basin, many of which are isolated due to passage impediments (Beamesderfer et al. 2004). Currently, green sturgeon are known to range from Baja California, Mexico, to the Bering Sea, Alaska, along the North American continental shelf. During late summer and early fall, subadults and non-spawning adult green sturgeon can frequently be found aggregating in estuaries along the Pacific coast (Emmett et al. 1991; Moser and Lindley 2007). In waters inland from the Golden Gate Bridge in California, sDPS green sturgeon are known to range through the estuary and Sacramento–San Joaquin River Delta (Delta) and up the Sacramento, Feather, Stanislaus, San Joaquin, and Yuba rivers (Israel et al. 2009; S.P. Cramer & Associates 2011; Seesholtz et al. 2014; Anderson et al. 2018; Root et al. 2020).

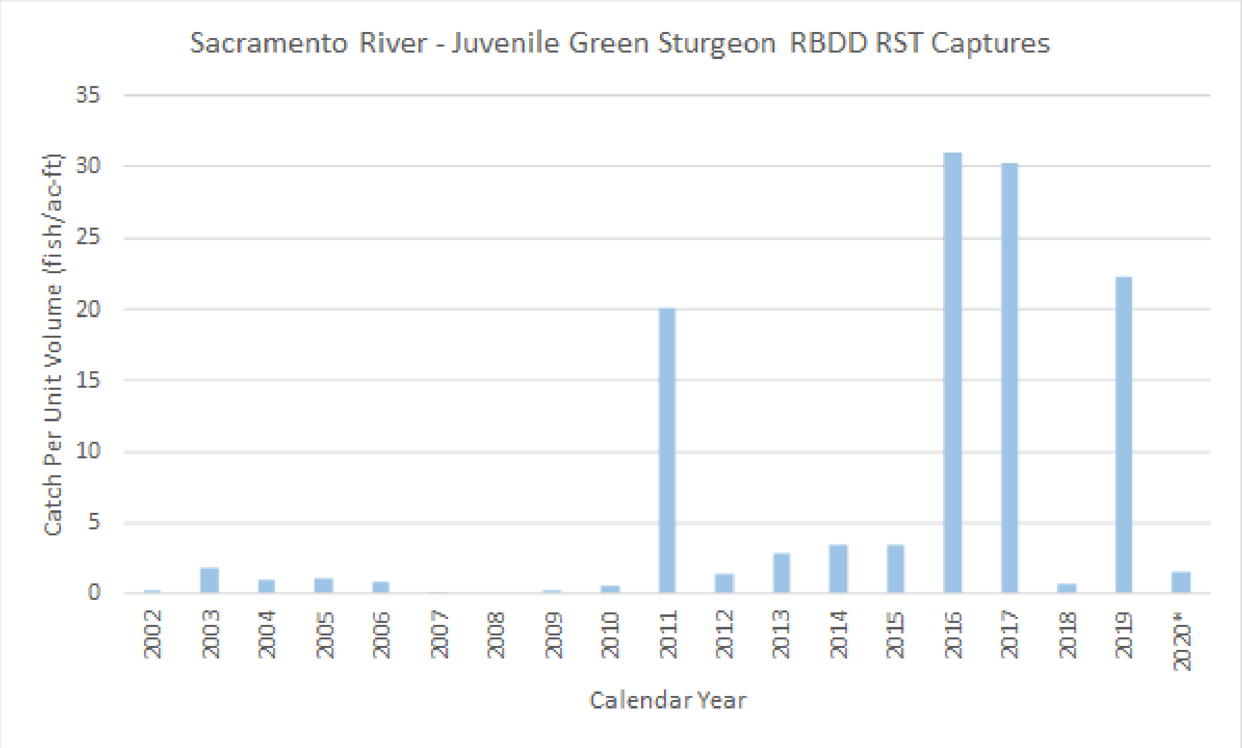
Few data exist regarding long-term trends in green sturgeon abundance. NMFS (2021), based on Mora et al. (2018) and the Southwest Fisheries Science Center unpublished data, reported that estimated upper Sacramento River spawner counts trended upward from 2010 to a peak of 530 individuals in 2014, followed by a decreasing trend through 2019 (Figure 8-1).



Source: National Marine Fisheries Service 2021.

Figure 8-1. Green Sturgeon Spawner Abundance Estimates, Upper Sacramento River, 2010–2019.

Green sturgeon juvenile abundance has been monitored in rotary screw traps (RSTs) at the former location of the Red Bluff Diversion Dam since 2002 by the U.S. Fish and Wildlife Service (USFWS) (Poytress et al. 2014; Voss and Poytress 2022). Abundance, measured as catch per unit volume (CPUV), was consistently <3 fish/acre-foot before 2011, but near or greater than 3 fish /acre-foot in most years since 2011, including 4 years during which CPUV exceeded 20 fish/acre-foot (Figure 8-2). The Red Bluff Diversion Dam gates have been open since 2011 and the facility was permanently decommissioned in 2013.

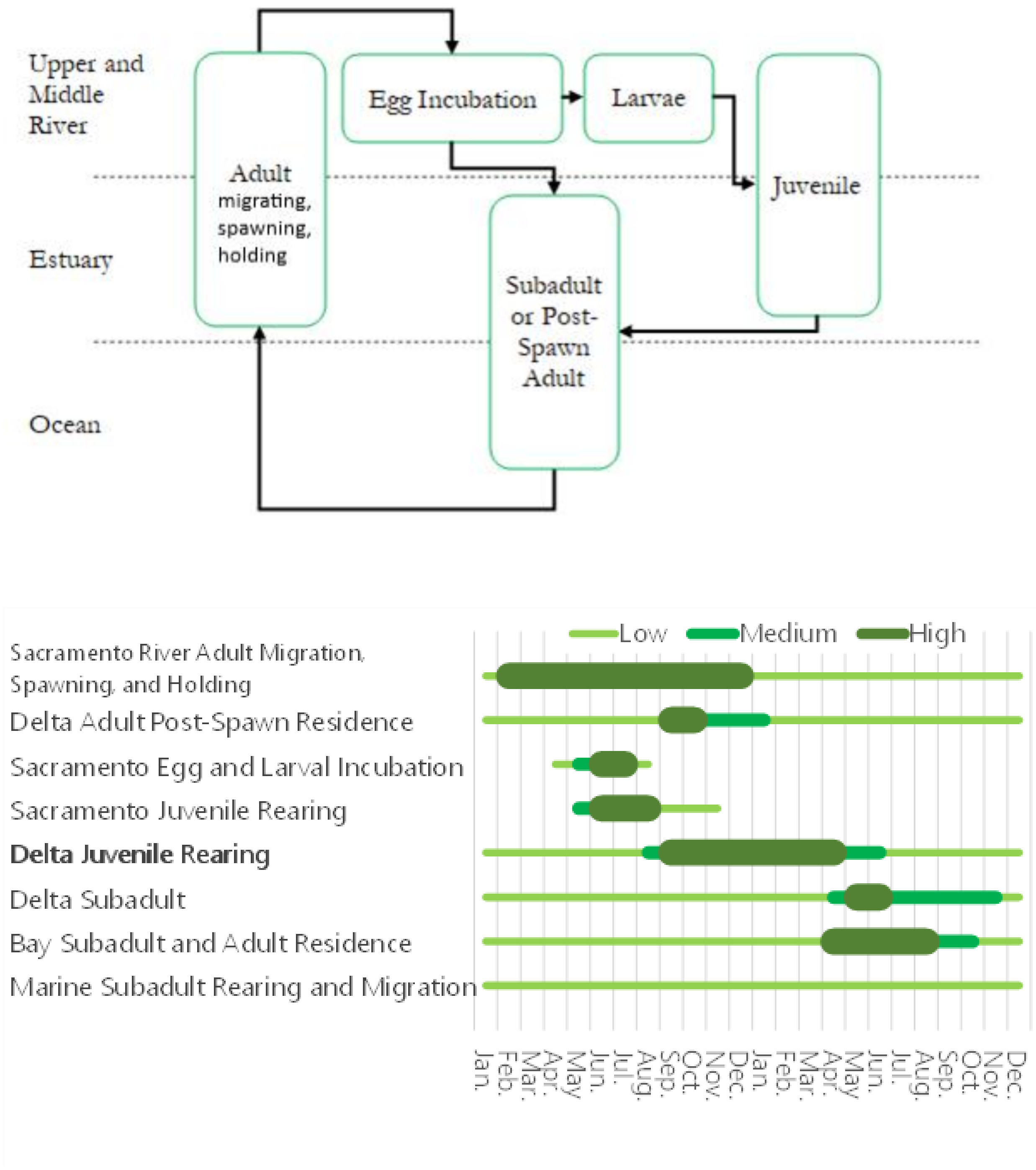


Sources: Poytress et al. 2014; Voss and Poytress 2022.
* Incomplete data collection due to COVID-19.

Figure 8-2. Juvenile Green Sturgeon Catch Per Unit Volume, Red Bluff Diversion Dam Rotary Screw Traps, 2002–2020.

The sDPS of green sturgeon is composed of a single, independent population, which principally spawns in the mainstem Sacramento River (Israel et al. 2009).

8.1.2 Life History and Habitat Requirements



Source: Developed from Heublein et al. 2017b.

Figure 8-3. Geographic Life Stage Domains for Green Sturgeon.

The sDPS green sturgeon spawn primarily in the Sacramento River from April to July, with the farthest upstream spawning event in the Sacramento River documented near Ink's Creek at river mile 264 (Poytress et al. 2015). Elevated Delta outflow is a likely spawning cue for mature adults to enter the river system. Adult green sturgeon begin to enter the Delta in February during the initiation of their upstream spawning run (Heublein et al. 2009; Moyle et al. 1995). The peak of adult entrance into the Delta appears to occur in March, with fish arriving upstream of the Glen-Colusa Irrigation District's water diversion on the upper Sacramento River in April and May to access known spawning areas (Moyle 2002). Following spawning, adults may remain in the Sacramento River Basin for up to a year; elevated water flows in the late fall and winter signal outmigration in adults that over-summer in spawning habitats (Moser et al. 2016; Miller et al. 2020). Adults continue to enter the Delta until early summer (June-July) as they move upriver to spawn in the upper Sacramento River basin. Some adult green sturgeon move back downstream as early as April and May through the Delta region, either as early post-spawners or as unsuccessful spawners. The majority of post-spawn adult green sturgeon will move down river to the Delta during the fall through winter.

Fish that over-summer in the upper Sacramento River will move downstream when the river water cools and rain events increase the river's flow and either hold in the Delta or migrate directly to the ocean. Juvenile green sturgeon migrate to the sea when they are one to four years old (Moyle et al. 1995). Juveniles were collected year-round in the Delta during a one-year study in 1963-1964 (Radtke 1966). The mainstem Sacramento River and Delta serve as rearing habitat and a migratory corridor for this species. Some rearing also may occur in the lowest reaches of the lower American River where deep pools occur for rearing of older life stages (downstream of State Route 160 bridge) (Thomas et al. 2013). Juvenile green sturgeon rear up to four years in the Delta and San Francisco Estuary before entering the ocean as sub-adults. Around age 15, mature adults migrate into the San Francisco Estuary in late winter through early spring to spawn in the Sacramento River and its tributaries primarily from April to July, and generally, adults spawn every three to four years (Range two-six years). Green sturgeon reach maturity around age 15 and can live to be 60-70 years old.

8.1.3 Limiting Factors, Threats, and Stressors

The viability of sDPS green sturgeon is constrained by factors including a small population size, lack of multiple populations, and concentration of spawning sites into few locations. The risk of extinction is believed to be moderate (National Marine Fisheries Service 2010). Although threats due to habitat alteration are thought to be high and indirect evidence suggests a decline in abundance, there is much uncertainty regarding the scope of threats and the viability of the population based on abundance indices (National Marine Fisheries Service 2010). Lindley et al. (2008), in discussing winter-run Chinook salmon, states that an ESU represented by a single population at moderate risk of extinction is at high risk of extinction over a large timescale. This assertion would apply to green sturgeon. The most recent five-year status review for sDPS green sturgeon found that some threats to the species have been eliminated, such as take from commercial fisheries, and removal of some passage barriers (National Marine Fisheries Service 2022). According to NMFS, many of the threats cited in the original listing still exist; thus, the threatened status of the DPS is still applicable (National Marine Fisheries Service 2022). Overall, NMFS considers the risk of extinction to be moderate because, although threats due to habitat alteration are thought to be high and the number of spawning adults is relatively low, the scope of threats and the accuracy of the population abundance estimates are uncertain (National Marine Fisheries Service 2018). However, the sDPS does not meet the definition of viable as an independent population having a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic diversity changes over a 100-year timeframe (McElhany et al. 2000).

To understand the Central Valley Project (CVP) and State Water Project (SWP) stressors on fish, SAIL models describe linkages between landscape attributes and environmental drivers to habitat attributes that may affect fish (stressors) based on life stage. The green sturgeon SAIL model provides life stages and hypothesized stressors, which are briefly summarized from Heublein et al 2017:

- **Adult to Spawning Adult**
    - Harvest: Harvest is a primary factor influencing subadult and adult abundance.
    - Food: Marine aggregation sites are related to foraging opportunities and food base (green sturgeon).
    - Water Temperature & Salinity: Water temperature influences timing of estuarine arrival and departure. Salinity influences subadult and adult distribution.
    - Toxicity & Dissolved Oxygen (DO): Adult abundance is influenced by food supply and/or food contaminant levels. There remains considerable uncertainty associated with determining the impacts of operations on the toxicity and dissolved oxygen stressor, particularly for impacts in the Delta.
    - Migration & Foraging Habitat: Habitat quality in the San Francisco estuary influences spatial distribution and abundance of adults.
    - Predation Risk: Adult sturgeon survival is affected by pinniped abundance and density.
- **Egg to Larvae**
    - Flow: Egg distribution and relative abundance are influenced by streamflow in spawning rivers.
    - Water Temperature: Egg distribution and relative abundance are influenced by temperature in spawning rivers.
    - Toxicity & DO: Contaminant levels in ovaries influence relative embryo and larval abundance. There remains considerable uncertainty associated with determining the impacts of operations on the toxicity and dissolved oxygen stressor, particularly for impacts in the Delta.
    - Incubation Habitat: Incubation habitat availability and quality influences relative embryo abundance and distribution.
    - Predation Risk: Embryo and larval survival is affected by predator community composition in incubation and rearing habitats.

- **Larvae to Juvenile**
    - Flow: Relative larval abundance is related to flow in spawning rivers.
    - Water Temperature: Relative larval abundance is related to temperature in spawning rivers.
    - Toxicity & DO: Contaminant levels in ovaries influence relative larval abundance. There remains considerable uncertainty associated with determining the impacts of operations on the toxicity and dissolved oxygen stressor, particularly for impacts in the Delta.
    - Entrainment Risk: Entrainment in diversions influences larval and juvenile survival.
    - Rearing Habitat: Larval distribution and relative abundance are related to habitat availability and quality.
    - Food: Relative larval abundance is influenced by food supply and/or food contaminant levels.
    - Predation Risk: Larval and juvenile survival is affected by predator community composition in incubation and rearing habitats.
- **Juvenile to Subadult/Adult**
    - Flow: Flows in spawning rivers are positively correlated to age-0 juvenile abundance.
    - Water Temperature & Salinity: Summer and fall flow and temperature in spawning rivers affects freshwater residency and temporal and spatial distribution of age-0 or age-1 juveniles. Juvenile residence duration in the San Francisco estuary is influenced by summer water temperatures and salinity.
    - Toxicity & DO: Water quality in juvenile dispersal and rearing habitat influences abundance. There remains considerable uncertainty associated with determining the impacts of operations on the toxicity and dissolved oxygen stressor, particularly for impacts in the Delta.
    - Entrainment Risk: Entrainment in diversions influences juvenile survival.
    - Rearing Habitat: Juvenile abundance is influenced by rearing habitat quality.
    - Food: Juvenile abundance is influenced by food supply and quality.
    - Predation Risk: Juvenile survival is affected by predator community composition in incubation and rearing habitats.
- **Spawning Adult to Egg and Post-Spawn Adult**
    - Harvest: Harvest and fishing regulations (e.g., catch and release in spawning habitat) influence run-size and spawning success.
    - Flow: Run-size and spawning distribution is influenced by flows in spawning rivers. Post-spawn migration and duration are affected by flow in spawning rivers.

    - Water Temperature: Run-size, spawning distribution, and spawning are influenced by water temperature in spawning rivers. Post-spawn migration and duration are affected by water temperature in spawning rivers. Elevated water temperature in spawning habitat influences atresia.
    - Toxicity & DO: Contaminant levels in ovaries influences fecundity. There remains considerable uncertainty associated with determining the impacts of operations on the toxicity and dissolved oxygen stressor, particularly for impacts in the Delta.
    - Barriers: Run-size and distribution are influenced by migration barriers.
    - Spawning Habitat: Spawning distribution is influenced by spawning habitat availability and quality.

8.1.4 Management Activities

The 2018 Recovery Plan developed five demographic criteria for recovery of Southern DPS green sturgeon. No reliable estimates of historical or current Southern DPS green sturgeon abundance exist, therefore adult abundance criteria were developed using the best available information from general principles in conservation biology relating population viability to abundance (National Marine Fisheries Service 2018). The plan also developed threat-based recovery criteria focused on barriers to migration, water flow and temperature, and contaminants, and entrainment (National Marine Fisheries Service 2018).

Efforts to salvage green sturgeon at the CVP and SWP have been conducted for decades; the number of green sturgeon observed in these facilities is typically low with a few individuals per year (National Marine Fisheries Service 2018f).

8.1.4.1 Recovery Plan Activities Related to the Long-Term Operation of the CVP and SWP

The following recovery and research focused management activities listed below, identified in the 2018 Recovery Plan, are focused on green sturgeon and are associated with the operation of the CVP and SWP or related facilities.

- **Sacramento River**
    - *Construct a structure that will provide volitional passage for upstream migrating adults at Fremont and Tisdale weirs.* This activity is partially completed with the construction of the Fremont Weir Adult Fish Passage Modification Project in 2018 and the ongoing construction of the Yolo Bypass Salmonid Habitat and Fish Passage Project – commonly referred to as the Big Notch Project – anticipated to be constructed in 2024. The Yolo Bypass Salmonid Habitat and Fish Passage Project is concurrent but separate from this consultation.
    - *Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.* This ongoing activity is addressed in concurrent, separate consultations.

    - *Conduct research to determine the effects on green sturgeon migration from the operations of the Delta Cross Channel gates.* This ongoing activity is addressed in concurrent, separate consultations.

8.1.4.2 Other Recovery Plan Activities

Additional recovery and research focused management activities identified in the 2018 Recovery Plan do not involve the operation of the CVP, SWP, nor related facilities. Some of these actions fall within additional U.S. Department of the Interior Bureau of Reclamation (Reclamation) and California Department of Water Resources (DWR) authorities to contribute to the recovery of listed species as project and programs with their own administration and consultation processes.

- **Sacramento River**
    - *Conduct research to evaluate sDPS spawning substrate suitability in the Sacramento River.* New research has been published on this topic, which was not incorporated into the 2018 Recovery Plan including Wyman et al 2017, Steel et al 2019, Klimley et al 2020, and Poytress et al 2015. This research was supported by Reclamation as part of a previous consultation. This activity has been completed.

8.1.4.3 Monitoring and Research

Trends in abundance of sDPS green sturgeon have been estimated from two long-term data sources: (1) salvage numbers at the State and Federal pumping facilities, and (2) incidental catch of green sturgeon by the California Department of Fish and Wildlife white sturgeon sampling/tagging program. Historical estimates from these sources are expected to be unreliable, as sDPS green sturgeon were likely not accounted for in incidental catch data, and salvage does not capture range-wide abundance in all water year types. Recently, more rigorous scientific inquiry has been undertaken to generate abundance estimates (Israel and May 2010; Mora et al. 2018). A decrease in sDPS green sturgeon abundance has been inferred from the amount of take observed at the south Delta pumping facilities: the Skinner Fish Protective Facility and the Tracy Fish Collection Facility. The salvage data likely indicate a high production year versus a low production year qualitatively but cannot be used to rigorously quantify abundance.

Since 2010, more robust estimates of sDPS green sturgeon have been generated. As part of a doctoral thesis at University of California, Davis, Ethan Mora used acoustic telemetry as well as Dual-frequency identification sonar (DIDSON) to locate green sturgeon in the Sacramento River and to derive an adult spawner abundance estimate (Mora et al. 2018). Results of these surveys were used to estimate an average annual spawning run of 223 (DIDSON) and 236 (telemetry) fish. These surveys have recently been used to generate an adult sDPS green sturgeon abundance estimate of 2,106 (95 percent confidence interval [CI] = 1,246 –2,966; (Mora et al. 2018)). Mora et al. (2018) applied a conceptual demographic structure to the above adult population estimate and generated a subadult sDPS green sturgeon population estimate of 11,055 (95 percent CI = 6,540 – 15,571). These estimates do not include the number of spawning adults in the lower Feather or Yuba rivers, where green sturgeon spawning was recently confirmed (Seesholtz et al. 2014).

Table 8-1. Summary of Green Sturgeon Take and Mortality by Life Stage, 2020.

Green Sturgeon – 2020	Sum of Expected Take	Sum of Actual Take	Sum of Indirect Mortality	Sum of Actual Mortality
Adult	70	0	1	0
Juvenile	758	2	28	0
Larvae	10000	157	900	7
Not Specified	0	8	0	0
Grand Total	**10828**	**167**	**929**	**7**

Table 8-2. Summary of Green Sturgeon Take and Mortality by Life Stage, 2021.

Green Sturgeon – 2021	Sum of Expected Take	Sum of Actual Take	Sum of Indirect Mortality	Sum of Actual Mortality
Adult	70	0	1	0
Juvenile	764	11	29	0
Larvae	10000	1037	900	65
Not Specified	0	4	0	0
Grand Total	**10834**	**1052**	**930**	**65**

Table 8-3. Summary of Green Sturgeon Take and Mortality by Life Stage, 2022.

Green Sturgeon – 2022	Sum of Expected Take	Sum of Actual Take	Sum of Indirect Mortality	Sum of Actual Mortality
Adult	70	0	1	0
Juvenile	764	18	29	0
Larvae	10000	0	900	0
Not Specified	0	0	0	0
Grand Total	**10834**	**18**	**930**	**0**

8.1.5 Current Incidental Take Statement

Quantitative incidental take for the 2019 NMFS Biological Opinion on Long term Operation of the CVP and SWP are described below.

- **Adult to spawning adult**
    - In the Sacramento River, no incidental take was reasonably expected to occur for adult green sturgeon.
    - In the Delta, incidental take of green sturgeon was reasonably expected to occur during the Barker Slough Sediment and Weed Control Operations. NMFS established an anticipated level of two green sturgeon entrained.
    - In the Delta, incidental take of green sturgeon was reasonably expected to occur during the Clifton Court Forebay Predator Electrofishing Study and Predatory Fish Relocation Study. NMFS established an anticipated level of 20 adults and juveniles (two-year non-lethal incidental take).
    - In the Delta, incidental take for adult green sturgeon was reasonably expected to occur due to the *Delta Cross Channel Gate Operations*. NMFS cannot precisely quantify and track the amount of individuals that are reasonably expected to be taken per species because there are no site-specific monitoring programs available at the Delta Cross Channel that would allow for quantification. The ecological surrogate is the frequency and duration of opening the Delta Cross Channel gates in the October through January time period. The anticipated level of take for the *Delta Cross Channel Gate Operations* would be meeting the number or duration of openings described in the 2019 NMFS Biological Opinion Proposed Action.
- **Egg to Larvae**
    - In the Sacramento River, no incidental take was reasonably expected to occur for eggs.
    - Eggs are not present in the Delta.
- **Larvae to Juvenile**
    - In the Sacramento River, no incidental take was reasonably expected to occur for larvae.
    - Larvae are not present in the Delta.
- **Juvenile to subadult/adult**
    - In the Sacramento River, no incidental take was reasonably expected to occur for juveniles.
    - In the Delta, incidental take of juvenile green sturgeon was reasonably expected to occur during operation of the CVP and SWP pumping facilities. NMFS established an anticipated level of 74 juveniles of green sturgeon entrained.

    - In the Delta, incidental take of green sturgeon was reasonably expected to occur during the Barker Slough Sediment and Weed Control Operations. NMFS established an anticipated level of two green sturgeon entrained.
    - In the Delta, incidental take of green sturgeon was reasonably expected to occur during the Clifton Court Forebay Predator Electrofishing Study and Predatory Fish Relocation Study. NMFS established an anticipated level of 20 adults and juveniles (two-year non-lethal incidental take) and three juveniles (lethal incidental take)
- **Spawning Adult to Egg and Post-Spawn Adult**
    - In the Sacramento River, no incidental take was reasonably expected to occur for spawning adults.

The 2019 NMFS Biological Opinion additionally included elements of the Proposed Action as ecological surrogates but did not quantify the effects by life stage.

8.2 Effects Analysis

The following sections summarize potential effects to green sturgeon by life stage and stressors from the Salmon and Sturgeon Assessment of Indicators by Lifestage (SAIL) conceptual model (Heublein et al. 2017b). Appendix B, *Water Operations and Ecosystem Analyses*, shows how the seasonal operation of the CVP and SWP change river flows, water temperatures, and water quality parameters in different locations and under different hydrologic conditions. Appendix C, *Species Spatial-Temporal Domains*, summarizes when fish may be present in different locations based on historical monitoring in the Central Valley.

Appendix D, *Seasonal Operations Deconstruction*, analyzes potential stressors for the seasonal operation of the CVP and SWP. Deconstruction of the seasonal operations systematically evaluated how each stressor identified by the SAIL conceptual models may or may not change from the proposed operation of CVP and SWP facilities to store, release, divert, route, or blend water. Stressors not linked to the operation of the CVP and SWP were identified as “not anticipated to change.” Stressors that may change to an extent insignificant or discountable were documented. Insignificant effects relate to the size of the impact and should never reach the scale where take occurs. Based on best judgment, a person would not be able to meaningfully measure, detect, or evaluate insignificant effects. Discountable effects are those extremely unlikely to occur. Based on best judgment, a person would not be able to expect discountable effects to occur.

Stressors exacerbated by the Proposed Action that may result in effects to listed species were documented and proposed conservation measures were identified. Appendix G, *Specific Facility and Water Operations Deconstruction*, analyzes potential stressors due to facility specific operations, and Appendices H through R analyze conservation measures to minimize or compensate for adverse effects.

8.2.1 Adult Migration, River Spawning, and Holding

Adult green sturgeon enter the San Francisco Estuary from the Pacific Ocean to begin their upstream spawning migration between February and May with a peak presence in the Delta in March. Once entering the San Francisco Estuary at the Golden Gate Bridge, green sturgeon travel over 400 river kilometers through the Delta and Sacramento River to the spawning grounds (Colborne et al. 2022).

Spawning in the Sacramento River occurs in the spring to early summer months from the Glen Colusa Irrigation District Diversion near Hamilton City up to Redding near the Keswick Dam in water depths of 8-9 meters (Wyman et al. 2018; Thomas et al. 2014; Klimley et al. 2015; Poytress et al. 2015). After spawning green sturgeon may immediately out-migrate through the Delta in the late spring to early summer months or hold in the Sacramento River until the late fall to early winter months, then out-migrate. Flow rates may dictate if post spawning adult green sturgeon will out-migrate or hold in the river (Colborne et al. 2022). Miller et al. (2020) observed adult green sturgeon in the Sacramento River during all months of the year, potentially due to late out-migrants overlapping with early in-migrants.

Adult green sturgeon migration, spawning, and holding data are limited for the Delta and Sacramento River.

The Proposed Action is not anticipated to change the stressors: *barriers, food, harvest, migration and foraging habitat, predation risk*, or *spawning habitat*. Conclusions are explained in Appendix D.

Stressors that may change at a level that is insignificant or include:

- The Proposed Action may increase or decrease the *flow* stressor. During the adult migration, spawning, and holding period, the Proposed Action will store and divert water in the winter resulting in decreased flows. In the summer, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Flow is not identified as a stressor for adult green sturgeon within the Delta (Heublein et al. 2017a).

  Increased flows in the Sacramento River during the summer could affect adult holding and cue riverine outmigration. River discharge is hypothesized to cue “late” outmigrating adult green sturgeon in the winter, meaning lower minimum daily flows in the winter could impact the duration of post spawning holding or timing of adult outmigration. However, adult green sturgeon have been observed in the Sacramento River year-round, with some individuals holding in the river for over a year. This behavior indicates the species’ ability to change outmigration strategies based on river discharge patterns (Colborne et al. 2022). If flows decrease in the winter, sturgeon may hold until the following year or be cued based on precipitation rather than managed flows. If flows increase during the summer it may cue sturgeon to outmigrate. It is likely green sturgeon adjust their holding times based on minimum discharge rates regardless of season (Colborne et al. 2022).

- The Proposed Action may increase or decrease the *toxicity* stressor and is not anticipated to change the *dissolved oxygen* stressor. During the adult migration, spawning, and holding period, the Proposed Action will store and divert water in the winter and spring and decrease flows. In the summer and fall, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. The Proposed Action will also decrease inflow into the Delta in the winter and spring and increase inflow in the summer. Reduced flows may concentrate contaminants if, and when, contaminants are present, and increased flows may dilute contaminants. Increased flows and pulses may mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor through deposited pollutants in dust, though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017, Chen et al. 2018).

  The toxicity stressor may increase in the Delta. CVP and SWP storage and diversion of water decreases Delta inflow and outflow limiting the potential for dilution of contaminants; however, CVP and SWP operations is not a proximate cause of contaminants mobilized from the watershed, agricultural lands, and urban effluent. Adult green sturgeon do not spend a substantial portion of their life foraging in the Bay-Delta (Heublein et al. 2017a).

  As benthic feeders, green sturgeon are hypothesized to be more susceptible to ingesting toxins; however, their foraging behaviors are not well documented in the Sacramento River. CVP and SWP operations are not a proximate cause of contaminants mobilized from the watershed, agricultural lands, and urban effluent.

  Dissolved oxygen less than 5.0 milligrams per liter (mg/L) may affect migration of other large bodied anadromous fishes (Carter 2005). Reclamation's water quality monitoring have not shown dissolved oxygen at levels below this in the winter, spring, summer, or fall in the Bay Delta or Sacramento River.

- The Proposed Action may decrease the *water temperature* stressor in the Sacramento River and increase or decrease the *water temperature* stressor in the Bay Delta. In the Sacramento River during the adult migration, spawning, and holding period, the Proposed Action will store and divert water in the spring and decrease flows. During summer and fall months, the Proposed Action will release water and increase flows. Spring, summer, and fall water temperatures resulting from the Proposed Action are within the observed migration and spawning temperature ranges.

  In the Bay Delta during the adult migration, spawning, and holding period, the Proposed Action will store and divert water and decrease Delta inflow during spring months and the month of November. During summer months and the months of September and October the Proposed Action will release water and increase Delta inflow.

  Delta water temperature may be negatively correlated with Delta inflow (Bashevkin and Mahardja 2022); however, the effect is limited (Wagner et al. 2011, Cloern et al. 2011, Jassby et al. 2008a, 2000b, Kimmerer 2004). Seasonal operations increase Delta inflow during the summer and fall due to lower contributions from precipitation and snowmelt. However, in the Delta water temperature is mainly driven by timing of snowmelt (Knowles and Cayan 2002, Wagner et al. 2011, Cloern et al. 2011), air temperature and meteorology (Vroom et al. 2017, Daniels and Danner 2020). There is uncertainty about whether a change in Delta inflow causes a change in Delta water temperatures.

The decrease in water temperature stressors in the Sacramento River is insignificant. Maintenance of Shasta Reservoir storage may result in warmer water temperatures in March and April and cooler water in May; however, very little is known about the thermal requirements of adult green sturgeon (Rodgers et al. 2019). While there is uncertainty regarding whether water temperature serves as a migration cue, Colborne et al. (2022) observed migration between 52 degrees Fahrenheit (°F) and 59°F (11 degrees Celsius [°C]) and 15°C) in the Sacramento River, and migration occurred mainly in the spring and fall. Spawning of green sturgeon in the Sacramento River has occurred between 49°F and 64°C (9.6°C and 17°C) in the spring months (Poytress et al. 2015).

- The Proposed Action may increase or decrease the *salinity* stressor in the Delta. Increased inflows in September and October and decreased inflows in November, winter months, and spring months may alter the amount of brackish habitat in the Delta. The Salinity stressor is not anticipated to change in the Sacramento River because green sturgeon present in the Sacramento River upstream of the Bay-Delta would not be anticipated to experience high salinity concentrations.

  Adult Green Sturgeon are hypothesized to use a broad range of habitats and water quality conditions. A telemetry study in the Delta detected green sturgeon at salinities between 8.8-32.1 parts per thousand (ppt), with no specific salinity preferences (Kelly et al. 2007).

There are no changes in stressors likely to harm, harass, or kill individuals during adult migration. The Proposed Action is not expected to result in incidental take during this life stage.

8.2.2 Egg Incubation

Green sturgeon eggs have been observed in the Sacramento River from the Glenn-Colusa Irrigation District Diversion to Cow Creek in Anderson, California (Poytress et al. 2015). The egg incubation period typically begins in April and lasts through June (Poytress pers. Comm.). Eggs are typically found in medium gravel substrates at an average depth of 8-9 meters in water temperatures between 52-63°F (11-17°C, Wyman et al. 2018, Poytress 2015). Green sturgeon eggs are not present in the Delta; therefore, the Delta is not considered for this life stage.

The Proposed Action is not anticipated to change the egg incubation stressors: *flow* nor *predation risk*. This conclusion is explained in Appendix D.

Stressors that may change at a level that is discountable and/or insignificant include:

- The Proposed Action may increase or decrease the *incubation habitat* stressor. During the egg incubation period, the Proposed Action will store and divert water in the spring and decrease flows in the Sacramento River below Keswick Dam. During the summer, the Proposed Action will release water and increase flows in the Sacramento River between Keswick Dam and Bend Bridge.

Decreased flows may be occasionally low near Keswick Dam to maintain winter-run Chinook salmon habitat quality, although green sturgeon have only been documented to spawn as far north as the confluence with Cow Creek, south of Clear Creek. Increased flows in the summer may provide environmental conditions favorable to eggs and developing embryos. Flows between 269-396 cubic meters per second are sufficient to maintain clean gravel and reduce the risk of suffocation by sand deposition (Poytress et al. 2015). The Proposed Action results in flows within this range.

- The Proposed Action may increase or decrease the *toxicity and dissolved oxygen* stressor. During the egg incubation period, the Proposed Action will store and divert water in the spring and decrease flows in the Sacramento River below Keswick Dam. During the summer, the Proposed Action will release water and increase flows in the Sacramento River between Keswick Dam and Bend Bridge. Reduced flows may concentrate contaminants if, and when contaminants are present and increased flows may dilute contaminants. Increased flows and pulses may mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor through deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017, Chen et al. 2018).

  Water quality monitoring in the upper Sacramento River has not shown contaminants or dissolved oxygen at levels likely to affect eggs and no fish effects have been observed in Red Bluff Diversion Dam fish monitoring, where juvenile green sturgeon are annually observed. During incubation, the embryos obtain nutrition from the yolk sac, which reduces their exposure to contaminants in prey during this life stage. Very little is known about dissolved oxygen stressors in eggs.

Described below are stressors exacerbated by the Proposed Action, potentially resulting in incidental take. Also described below are conservation measures included as part of the Proposed Action to avoid or compensate for adverse effects. Finally, the Proposed Action may also ameliorate certain stressors prevalent in the environmental baseline, and a description of these beneficial effects is provided below.

8.2.2.1 Water Temperature

The proposed blending and release of water may generally decrease the water temperature stressor. During the egg incubation and larval emergence, the Proposed Action will blend water from Shasta Reservoir and import water from Trinity Reservoir to manage temperatures below Keswick Dam. Spring water temperatures resulting from the Proposed Action will likely increase in March and decrease in May resulting in temperatures closer to the optimal thermal range. Summer water temperatures under seasonal operations are likely within these observed optimal thermal ranges as well. Warmer water temperatures at and downstream of RED BLUFF DIVERSION DAM could be associated with a more limited spawning habitat for green sturgeon (Heublein et al. 2017a). Appendix L – Shasta Coldwater Pool presents an analysis of this stressor.

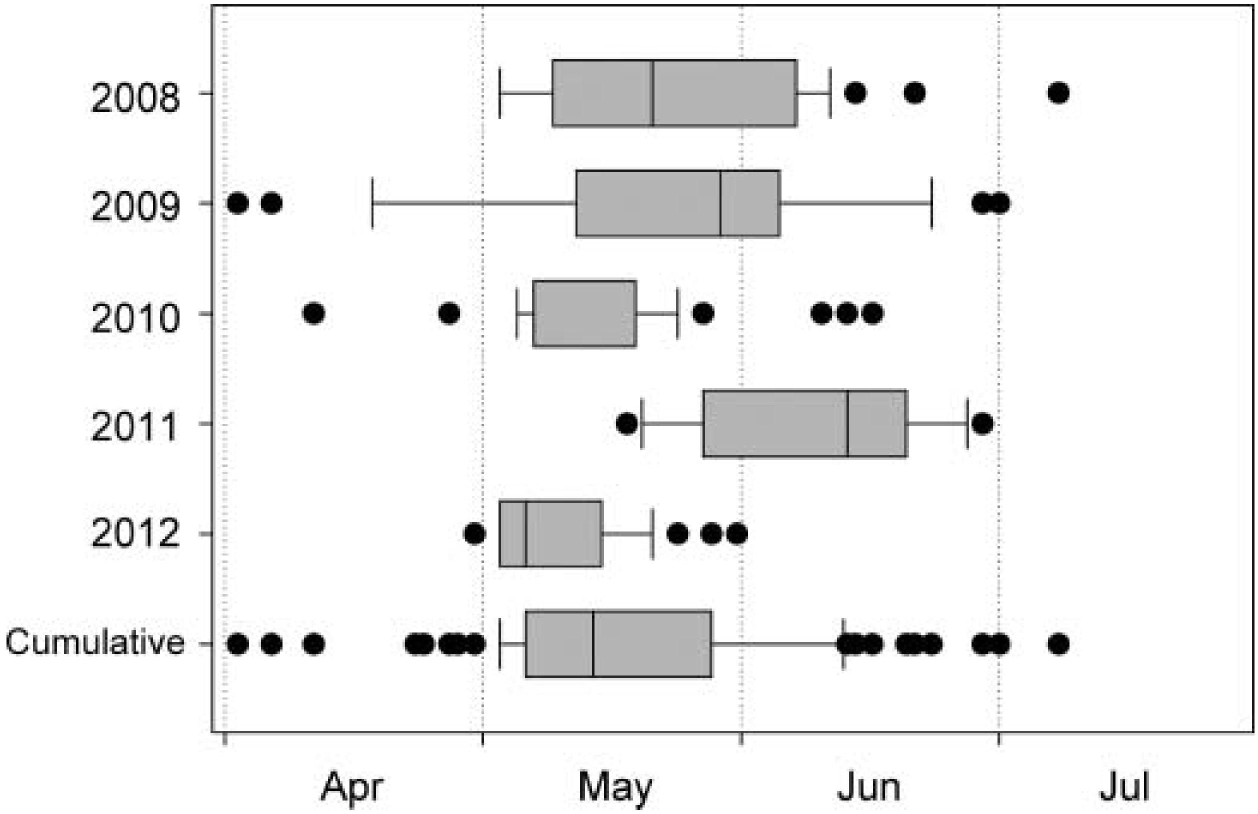
The decrease in water temperature stressor is expected to be **beneficial**. Water temperatures resulting from the Proposed Action are more likely to be in the beneficial range during the egg incubation period.

The Proposed Action may decrease the water temperature stressor for green sturgeon egg incubation that exists in the **environmental baseline** (without the Proposed Action). The water temperature stressor is mainly driven by timing of snowmelt (Knowles and Cayan 2002, Wagner et al. 2011, Cloern et al. 2011), air temperature and meteorology (Vroom et al. 2017, Daniels and Danner 2020). It is expected that climate change will result in warmer air temperature and shift in forms of precipitation, with more precipitation falling as rain, which will exacerbate water temperatures in the reservoirs.

Keswick and Shasta dams altered historical spawning habitat by disrupting natural water flows and fundamentally changing water temperature processes by resetting the upstream temperature boundary condition below Keswick Dam (Daniels and Danner 2020). Green sturgeon spawn in the Sacramento River below Keswick Dam.

Red Bluff Diversion Dam gates have been permanently open year-round since 2012, giving sturgeon access to a wider range of water temperatures during the migration and spawning period.

The **proportion** of the population affected by the Proposed Action depends on spawning timing and distribution of eggs and is **likely large**. Water temperature stressors depend on hydrology, meteorology, storage in Shasta and Trinity reservoirs, releases from Keswick Reservoir, operation of the Temperature Control Device, spawning timing, and distribution of eggs. Eggs have typically been found from April through July (Figure 8-4) in the Sacramento River, meaning the entirety of the green sturgeon embryos, with the exception of the few that possibly hatch in the Feather and Yuba rivers, will be in the upper Sacramento River during this time period.



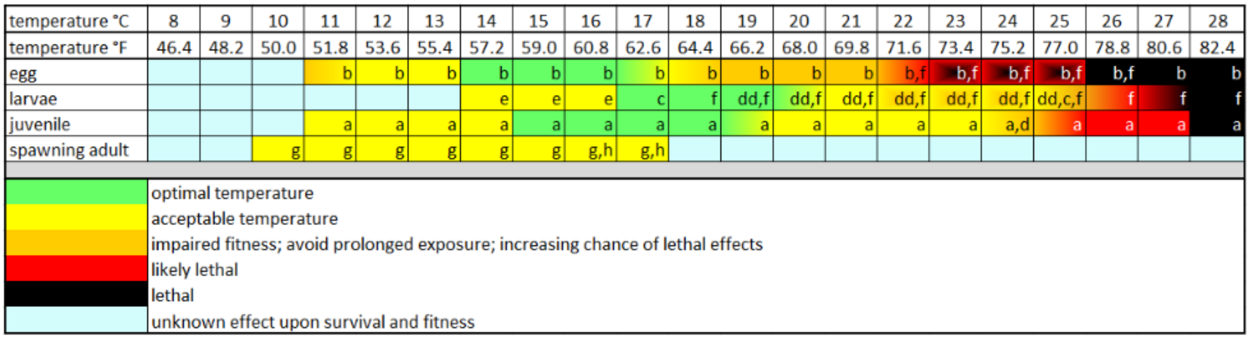
Source: Poytress et al. 2015.

Figure 8-4. Box Plots Displaying the Median and 10th, 25th, 75th, and 90th Percentiles with Outliers (Black Dots) of Annual Green Sturgeon Spawning Events (n = Egg Counts) on the Sacramento River for 2008 (n=42), 2009 (n=56), 2010 (n=105), 2011 (n=11), 2012 (n=59), and Cumulatively (n=273).

Literature does not uniquely inform the proportion of the population.

Datasets use historical conditions and observation to inform how green sturgeon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models.

Analyzing the effect of water temperature on egg incubation is complicated by the influence of flow and the potential positive relationship between high flows and egg distribution (Heublein et al. 2017b). Changes in flow operations in the winter, spring, and summer could affect spawning timing assuming that spawning individuals are cued by flow (Colborne et al. 2022). Spawning and egg habitat has been recently studied (Poytress et al 2015, Wyman et al. 2018, Steel et al. 2019, Zarri et al 2019, Klimley et al 2020) and modeling suggested spawning habitat is fairly constant with flow and spawning occurs early in the temperature management season prior to potential drought temperature impacts. Appendix L addresses water temperature related effects.



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											

🟩	optimal temperature
🟨	acceptable temperature
🟧	impaired fitness; avoid prolonged exposure; increasing chance of lethal effects
🟥	likely lethal
⬛	lethal
🟦	unknown effect upon survival and fitness

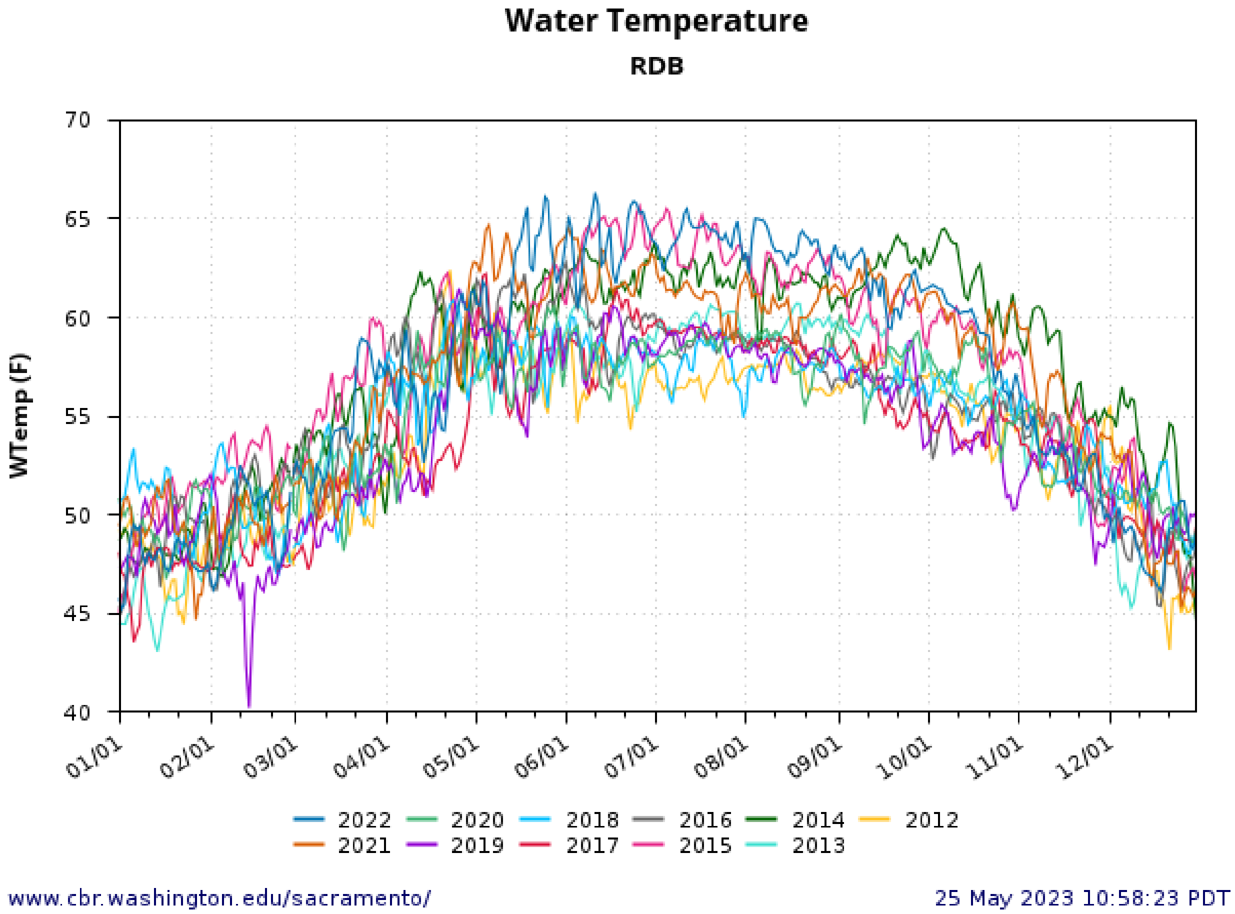
Source: Heublein et al. 2017a.
a = Mayfield and Cech 2004.
b = Van Eenennaam et al. 2005.
c = Werner et al. 2007.
d = Allen et al. 2006a.
e = Poytress et al. 2012.
f = Linares-Casenave et al. 2013.
g = Poytress et al. 2015.
h = Seesholtz et al. 2015
dd = Allen et al. 2006b.

Figure 8-5. Green Sturgeon Water Temperature Tolerances by Life Stage.

Laboratory studies involving 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 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 water 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).

Green sturgeon embryo hatching success is maximized between 57.2-62.6°F and acceptable between 52-63°F (Rogers et al. 2019; Van Eenennaam et al. 2005) (Figure 8-5). As seen in Figure 8-5, the upper temperature threshold has been studied and tested in primarily laboratory scenarios, while the lower water temperature threshold remains largely unknown for most life stages. In field studies, embryos have been collected on the Sacramento River between 52.3-60.3°F (11.3-15.8°C) (Brown 2007, Poytress et al. 2015).

Figure 8-6 shows historic water temperatures on the Sacramento River at Red Bluff Diversion Dam during the egg incubation period. Water temperatures were elevated during 2014, 2015, 2021, and 2022 when coldwater pool volume was diminished, and there was little available cold water left to release from Shasta Reservoir.



Source: Columbia Basin Research, University of Washington 2023.

Figure 8-6. Sacramento River Water Temperatures at Red Bluff Diversion Dam between January and December, 2012–2022.

Models provide quantitative estimates of future conditions under the Proposed Action. Modeled water temperatures (Hec-5Q) during green sturgeon egg incubation are as follows.

Results for the 52.3°F to 60.8°F range are presented in Table 8-4 for Bend Bridge and in Table 8-5 for Hamilton City. At Bend Bridge, the percentage of months outside the optimal temperature range was 0% for Above Normal and Below Normal water years for all three Proposed Action phases. For all other water year types, the percentage of months outside the range was between 1% and 9.8% under the Proposed Action phases.

Table 8-4. Percent of Months Outside the 52.3°F to 60.8°F Water Temperature Range Supporting Green Sturgeon Egg Incubation by Water Year Type and for All Years Combined, Sacramento River at Bend Bridge, April through July.

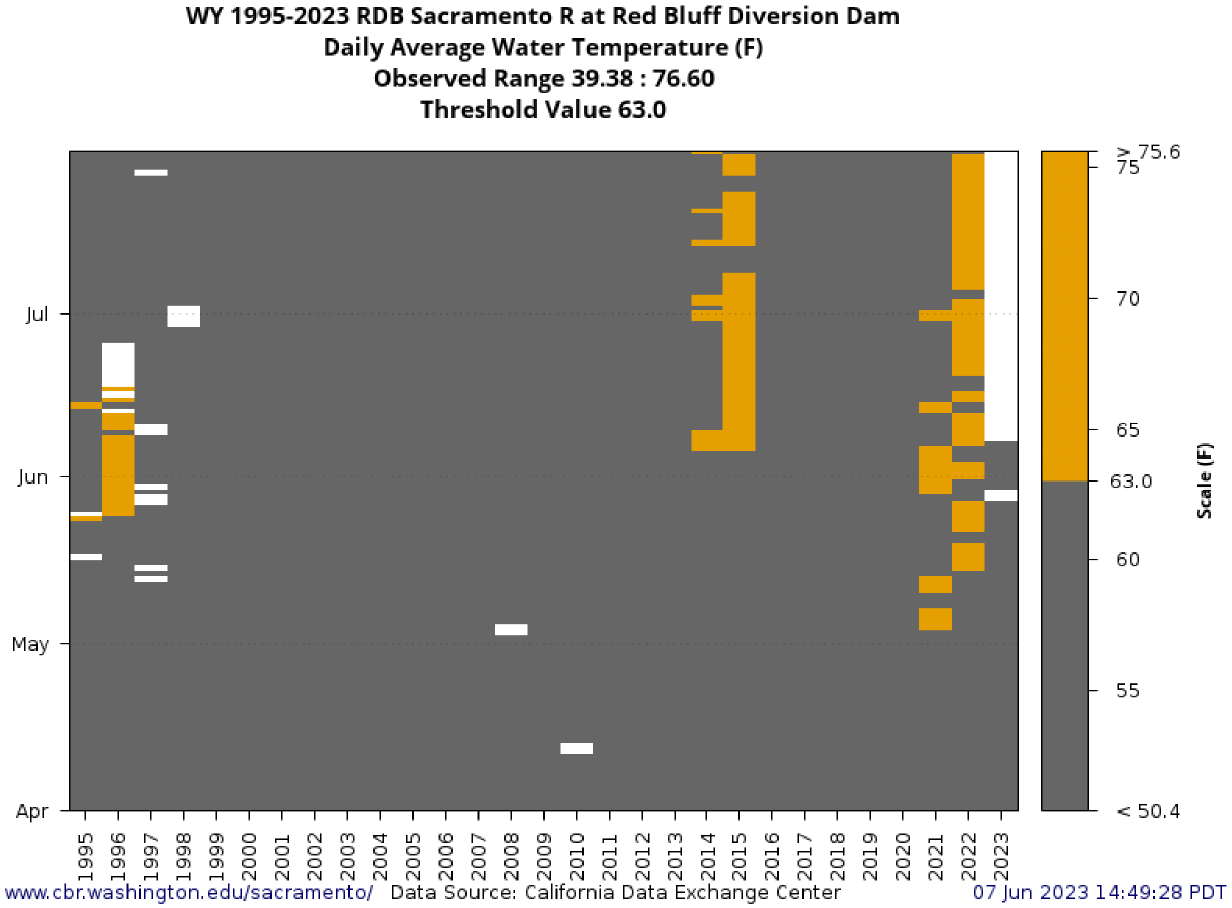
WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	54.5	17.9	9.8	8.9	8.9	9.8
AN	61.5	3.8	1.9	0.0	0.0	0.0
BN	70.8	2.8	1.4	0.0	0.0	0.0
D	68.8	3.1	3.1	1.0	2.1	2.1
C	76.6	4.7	4.7	1.6	4.7	6.3
All	65.4	7.6	4.8	3.0	3.8	4.3

At Hamilton City, the percentage of months outside the 52.3°F to 60.8°F range under the Proposed Action phases are between 66.1% during wet water years and 93.8% during critical water years. Overall, the percentage of months outside the range increased from wetter to drier water year types.

Table 8-5. Percent of Months Outside the 52.3°F to 60.8°F Water Temperature Range Supporting Green Sturgeon Egg Incubation by Water Year Type and for All Years Combined, Sacramento River at Hamilton City, April through July.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	71.4	76.8	68.8	67.0	66.1	66.1
AN	75.0	82.7	69.2	69.2	69.2	67.3
BN	80.6	87.5	70.8	70.8	73.6	72.2
D	86.5	95.8	81.3	81.3	85.4	85.4
C	92.2	96.9	96.9	93.8	92.2	90.6
All	80.6	87.4	76.8	75.8	76.8	76.0

The **frequency** of occurrence is **likely medium** and likely to occur annually in the Proposed Action. The water temperature stressor is dependent on coldwater pool availability and is affected primarily by hydrology and meteorology. Historically, Water temperatures at the Red Bluff Diversion Dam have exceeded the acceptable temperature range for successful hatching during the peak spawning months of May and June during 4 of the last 10 years, meaning 60% of the time water temperatures at Red Bluff Diversion Dam are acceptable for egg incubation throughout the incubation period (Figure 8-7). Note that water temperatures hit the threshold earlier in 2021 and 2022, both designated critically dry water years. (http://cdec4gov.water.ca.gov/reportapp/javareports?name=WSIHIST). The water temperature gage at Red Bluff Diversion Dam was chosen to evaluate this stressor because it sits in the middle of the green sturgeon spawning habitat on the Sacramento River.



Source: Columbia Basin Research, University of Washington 2023.
Threshold exceedances depicted in yellow. Unavailable data depicted in white.

Figure 8-7. Sacramento River Water Temperatures at Red Bluff Diversion Dam between April and July, 1995–2023.

8.2.3 Larvae

Green sturgeon larvae are present in the upper Sacramento River during spring and summer months. Larval green sturgeon are suspected to remain near their spawning grounds for about 16 days post hatch, when they begin a first nocturnal migration to disperse from their hatching site (Kynard et al. 2005). It is hypothesized that larval green sturgeon spend a period of time foraging in the upper river and may move upstream during the late summer and fall, rather than moving downstream to feed (Poytress et al. 2012). Green sturgeon larvae are not present in the Delta; therefore, the Delta is not considered for this life stage.

The Proposed Action is not anticipated to change the stressors *entrainment risk*, *rearing habitat*, and *predation*. See Appendix D.

Stressors that may change at a level that is insignificant or discountable include:

- The Proposed Action may increase or decrease the *flow* stressor. During the larval period, the Proposed Action will store and divert water in the spring and decrease flows. During the summer, the Proposed Action will release water and increase flows.

  Body condition in larval green sturgeon is negatively correlated with increased discharge (Zarri et al 2019). However, flow at the Red Bluff Diversion Dam has been positively correlated with larval abundance (Heublein et al. 2017b). Based on this information, larval green sturgeon may benefit from reduced flows and increased flows. Information on flow and requirements for rearing green sturgeon larvae continues to be limited and not well understood.

- The Proposed Action may increase or decrease the *toxicity and dissolved oxygen* stressor. During the larval period, Reclamation and DWR's proposed storage of water will decrease and increase flows on average in the Sacramento River below Keswick Dam. Reduced flows may concentrate contaminants and decrease dissolved oxygen concentrations. Reduced flows may concentrate contaminants if, and when contaminants are present and increased flows may dilute contaminants. Increased flows and pulses may mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor through deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017, Chen et al. 2018).

  Water quality monitoring has not shown contaminants at levels likely to affect larvae and no fish effects have been observed in fish monitoring. Water quality monitoring has not shown dissolved oxygen at low levels in the spring and summer. Very little is known about dissolved oxygen stressors in larvae.

- The Proposed Action may increase or decrease the *food* stressor. During the larval period, releases of Shasta Reservoir storage may increase flows in the summer. During the spring, the Proposed Action will store and divert water resulting in decreased flows.

  Increased flows on the Sacramento River have been observed to decrease prey taxon richness and abundance in diets of early life stage green sturgeon, especially the presence of cyclopoid copepods. Copepod abundance in the Sacramento River has been found to be inversely associated with discharge (Sommer et al. 2004). Green sturgeon larvae smaller than 30mm rely on benthic macroinvertebrates and zooplankton prey with a strong reliance on cyclopoid copepods. However, green sturgeon are also reliant on benthic macroinvertebrates through the larval life stage, including baetid mayflies (*Ephemeroptera baetidae*), chironomids (*Diptera chironomidae*), and simulids (*Diptera simuliidae*). Additionally, larval diet richness increases with total length, widening the prey selection (Zarri and Palkovacs 2018).

Described below are stressors exacerbated by the Proposed Action, potentially resulting in incidental take. Also described below are conservation measures included as part of the Proposed Action to avoid or compensate for adverse effects. Finally, the Proposed Action may also ameliorate certain stressors prevalent in the environmental baseline, and a description of these beneficial effects is provided below.

8.2.3.1 Water Temperature

The proposed, storage, blending and release of water may decrease the water temperature stressor. During the egg incubation and larval emergence, release of Shasta Reservoir storage associated with the Proposed Action may result in colder water temperatures in the spring and summer. Spring water temperatures resulting from Proposed Action storage and diversion indicate operations increase water temperatures in March to be more suitable for larvae and decrease water temperatures in May to fall below temperatures at which deformities have been observed. Summer water temperatures resulting from the Proposed Action releases indicate operations decrease water temperatures to be more suitable for larvae, maintaining water temperatures to less than 64.4°F. *Appendix L- The Shasta Reservoir Coldwater Pool Management Appendix* presents an analysis of this stressor.

The decrease in water temperature stressor is expected to be **beneficial**. Cooler water temperatures below the 64.4°F threshold may provide increased benefits to larval green sturgeon. Heublein et al. (2017b) found that larval abundance is likely linked to river flow and temperature in spawning rivers, as well as habitat availability and quality. Additionally, water temperatures are generally suppressed in the upper Sacramento River which may reduce predation by decreasing predator activity and appetite (bioenergetics).

In laboratory studies, water temperatures greater than 64.4°F (18°C) have been found to be detrimental to newly hatched larvae, with notochord deformities occurring between 68-78.8°F (20-26°C) (Linares-Casenave et al. 2013). Post yolk-sac larvae exhibited accelerated growth at higher temperatures 75.2°F (24°C) when food was maintained in the lab. In the field, yolk-sac larvae have been collected between 55.2-55.8°F (12.9 and 13.2°C) (Brown 2007, Poytress et al. 2015), but temperatures are held at approximately 56°F in these areas. Zarri et al. (2019) noted that warmer temperatures were associated with fuller stomachs and improved body condition but did not indicate an optimal temperature.

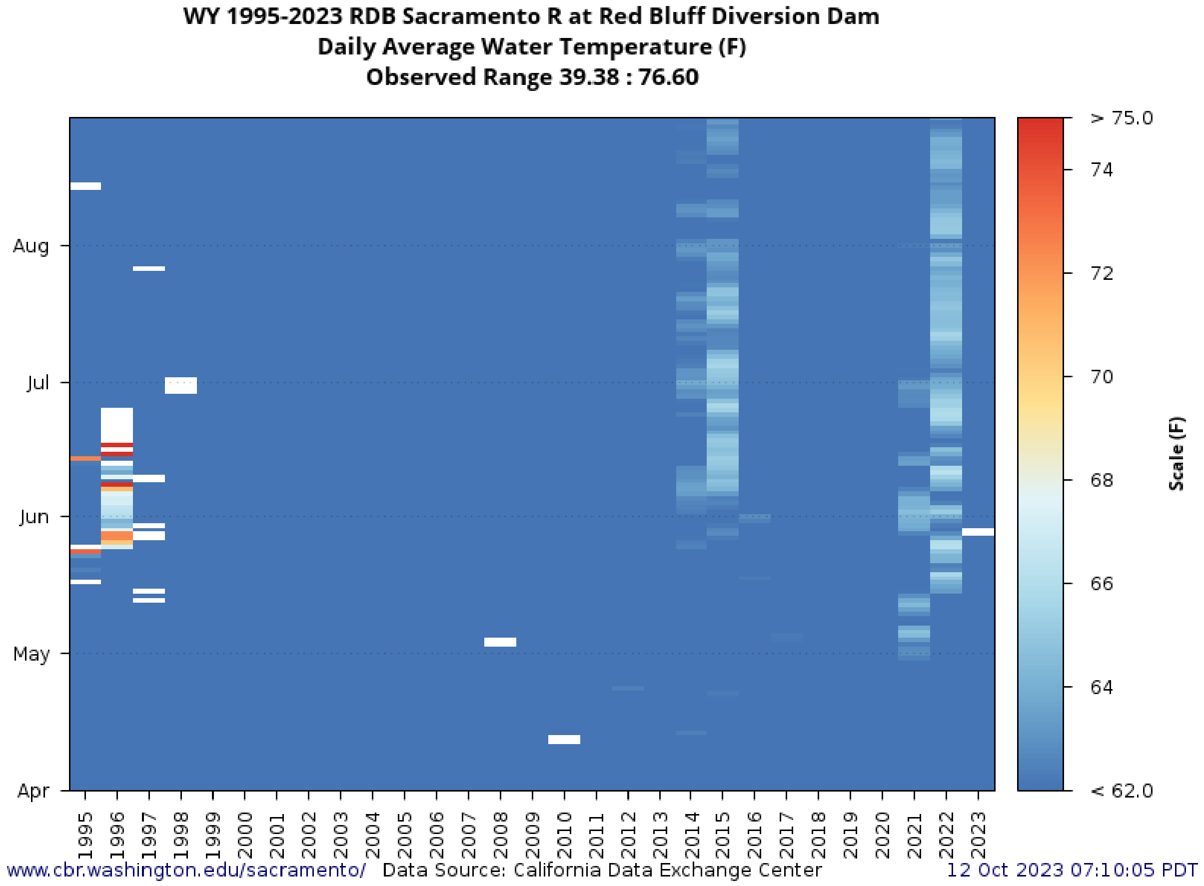
The Proposed Action may decrease the water temperature stressor for green sturgeon larvae that exists in the **environmental baseline** (without the Proposed Action). The water temperature stressor is mainly driven by timing of snowmelt (Knowles and Cayan 2002, Wagner et al. 2011, Cloern et al. 2011), air temperature and meteorology (Vroom et al. 2017, Daniels and Danner 2020). It is expected that climate change will result in warmer air temperature and shift in forms of precipitation, with more precipitation falling as rain, which will exacerbate water temperatures in the reservoirs.

Keswick and Shasta dams altered historical spawning habitat by disrupting natural water flows and fundamentally changing water temperature processes by resetting the upstream temperature boundary condition below Keswick Dam (Daniels and Danner 2020). Green sturgeon larvae rear in the Sacramento River below Keswick Dam.

The **proportion** of the population affected by the Proposed Action is **likely large**. Water temperature stressors depend on hydrology, meteorology, storage in Shasta and Trinity reservoirs, releases from Keswick Reservoir, operation of the TCD, and egg hatch timing. Larvae have historically been observed between May and August (Poytress et al. 2012), meaning the entirety of the sDPS green sturgeon larval population, with the exception of the few that possibly rear in the Feather and Yuba rivers, will be in the upper Sacramento River during this time period.

Literature does not uniquely inform the proportion of the population.

Datasets use historical conditions and observation to inform how green sturgeon may respond to the Proposed Action. Historical monitoring may support or refute hypotheses and informs the reasonableness of information generated by models. Figure 8-8 shows historic water temperatures on the Sacramento River at Red Bluff Diversion Dam during the larval period. Water temperatures were elevated during 2014, 2015, 2021, and 2022 when coldwater pool volume was diminished, and there was little available cold water left to release from Shasta Reservoir.



Source: Columbia Basin Research, University of Washington 2023.
White spaces signify no data.

Figure 8-8. Sacramento River Water Temperatures at Red Bluff Diversion Dam between April and August, 2012–2023.

Models provide quantitative estimates of future conditions under the Proposed Action.

Modeled water temperatures (Hec-5Q) during larval green sturgeon are as follows.

Results for the 64.4°F upper limit are presented in Table 8-6 for Bend Bridge and in Table 8-7 for Hamilton City. At Bend Bridge, the percentage of months above the limit for all water year types except Critically Dry water years was 0% under all three Proposed Action phases. For Critically Dry water years the percentage of months above the limit was 4.7% under the Proposed Action phases.

Table 8-6. Percent of Months Above the 64.4°F Upper Water Temperature Limit for Newly Hatched Green Sturgeon Larvae by Water Year Type and for All Years Combined, Sacramento River at Bend Bridge, May through August.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	71.4	0.0	0.0	0.0	0.0	0.0
AN	76.9	0.0	0.0	0.0	0.0	0.0
BN	81.9	0.0	0.0	0.0	0.0	0.0
D	82.3	0.0	0.0	0.0	0.0	0.0
C	89.1	0.0	4.7	4.7	4.7	4.7
All	79.5	0.0	0.8	0.8	0.8	0.8

At Hamilton City, the percentage of months above the upper water temperature limit ranged from 25% in Above Normal water years to 65.6% in Critically Dry water years under the Proposed Action phases. Overall, Wet water year and Critically Dry water year types had higher percentages of months above the optimal temperature limit.

Table 8-7. Percent of Months Above the 64.4°F Upper Water Temperature Limit for Newly Hatched Green Sturgeon Larvae by Water Year Type and for All Years Combined, Sacramento River at Hamilton City, May through August.

WYT	EXP1	EXP3	NAA	Alt2woTUCPwoVA	Alt2woTUCPDeltaVA	Alt2woTUCPAllVA
W	79.5	79.5	41.1	35.7	34.8	35.7
AN	92.3	78.8	28.8	26.9	26.9	25.0
BN	95.8	68.1	29.2	26.4	27.8	27.8
D	95.8	61.5	30.2	26.0	27.1	29.2
C	96.9	81.3	70.3	65.6	62.5	56.3
All	90.9	73.2	39.4	35.4	35.1	34.6

The **frequency** of occurrence is **likely medium**. The water temperature stressor is dependent on coldwater pool availability and is affected primarily by hydrology and meteorology. According to Figure 8-8, water temperatures were in the beneficial range of 62-68°F during the spring and summer months for four of the last 10 years, or 40% of the time. The rest of the time water temperatures were below 62 degrees for the duration of the larval life stage, which may be below the lower temperature threshold for larval green sturgeon.

8.2.4 Juveniles

Juveniles are present in the upper Sacramento River and the Bay Delta year-round. Not much is known about juvenile green sturgeon movements, and it is not clear when juvenile green sturgeon leave their birthplace upriver and migrate downstream to rearing habitats in the Delta. Gruber et al. (2022) recently estimated that juveniles would reach the migrant readiness stage at 180 days post hatch, based on research by Kynard et al. (2005). The timing of juvenile outmigration is reliant on their hatch date and can vary from early- to mid-October to January. Juveniles were detected making continuous and stepped migrations from the upper Sacramento River in Red Bluff, California, to the Delta. New research suggests that increases in reach discharge, paired with co-occurring turbidity and individual migrant readiness, may influence the initiation of juvenile downstream migration (Gruber et al. 2022); however, there is also a strong temperature-dependence for growth between 51.8 and 68°F (Hamda et al 2019). Findings by Thomas et al. (2022) suggest that juvenile green sturgeon are flexible in their movements in a highly variable environment. There is uncertainty about the effects of several of the stressors on juvenile green sturgeon as well as the distribution of juveniles where they could be affected by the stressors. Larvae are being used as a proxy for juveniles and it is unclear whether larval and juvenile life stages overlap significantly enough for the proxy to make sense.

The Proposed Action is not anticipated to change the stressor *rearing habitat* and *predation risk.* See Appendix D.

Stressors that may change at a level that is insignificant or discountable include:

- The Proposed Action may increase or decrease the *flow* stressor. During the juvenile rearing and outmigration period, the Proposed Action will release water and increase flows on average in the Sacramento River below Keswick Dam and inflow into the Delta and decrease Delta outflow due to downstream storage and diversions.

  Although decreased outflow and increased diversions may change the duration of juvenile residency, juvenile green sturgeon may occupy brackish and freshwater habitats in the Delta for up to one and a half years until they can tolerate seawater (Allen 2005, Poletto et al. 2013). Juveniles may remain in the Delta for up to three years based on capture of fish of this age in fish monitoring surveys and salvage. The long Delta residency of green sturgeon juveniles is unlikely to be influenced by seasonal changes in Delta flows.

  During the spring, the proposed storage under the Proposed Action in Shasta Reservoir may decrease flows, thereby increasing temperatures. Juvenile green sturgeon growth may increase with increased temperatures and decreased flows. On the other hand, increased releases of Shasta Reservoir storage may decrease water temperatures in the summer, and juvenile growth may decrease with lower temperatures and increased flows (Zarri et al. 2019). The combination of higher discharge and lower temperatures appears to reduce larval sturgeon body condition (Zarri et al. 2019) and may similarly impact juveniles during the summer months. However, rapid growth generally occurs in the juvenile life stage (Heublein et al. 2017a), and juvenile green sturgeon are strong enough swimmers to move to acceptable habitat.

- The Proposed Action may increase or decrease the *water temperature* stressor. During the juvenile outmigration and rearing period, CVP and SWP storage and diversion may increase or decrease Delta inflow.

  Delta water temperature is negatively correlated with Delta inflow in the spring (Bashevkin and Mahardja 2022) and reservoir operations may influence water temperature to a minimal extent in the lower reaches of the Sacramento River (Daniels and Danner 2020). Additionally, CVP and SWP storage and diversion of water decrease inflow in November, while summer seasonal operations increase Delta inflow. In the Delta, water temperature is mainly driven by timing of snowmelt (Knowles and Cayan 2002), air temperature and meteorology (Vroom et al. 2017, Daniels and Danner 2020). There is uncertainty about whether changes in Delta inflow cause changes in Delta water temperatures.

  Shaping of Shasta Reservoir storage may result in warmer water temperatures in the Sacramento River in March and April and cooler water in May. During the juvenile rearing and outmigration period, spring water temperatures resulting from the Proposed Action indicate operations increase temperatures in March to be closer to juvenile optimum water temperatures and decrease water temperatures in May to fall below optimal juvenile temperatures. Lab studies indicate juvenile bioenergetic performance to be optimal between 59-66.2°F (15-19°C) (Figure 8-5) (Mayfield and Cech 2004); however, young juveniles have been found to maintain swimming performance across a wider range of temperatures (Rodgers et al. 2019). Summer water temperatures under seasonal operations are within the above mentioned observed optimal water temperature ranges.

- The Proposed Action may increase or decrease the *salinity* stressor in the Bay Delta in the fall. Increased inflows in September and October and decreased inflows in November may alter the amount of brackish habitat in the Delta. It is hypothesized that changes in salinity may influence the distribution of juvenile green sturgeon (Heublein et al. 2017a). Juveniles were found to display a preference for seawater (Poletto et al. 2013). While exposure of young juveniles (<170 dph) to brackish water can negatively impact growth and survival, growth effects occur at salinities > 10 ppt, and survival effects occur at 20-30 ppt (Allen et al. 2011, Allen and Cech, 2007). Juvenile green sturgeon have a broad tolerance for salinity and are strong enough swimmers to move to acceptable habitat.

  The *salinity* stressor is not anticipated to change in the Sacramento River because green sturgeon present in the Sacramento River upstream of the Bay-Delta would not be anticipated to experience high salinity concentrations.

- The Proposed Action may increase or decrease the *toxicity and dissolved oxygen* stressor. During the juvenile rearing and outmigration period, CVP and SWP storage and diversion of water decreases flow in the Sacramento River, inflow into the Delta, and Delta outflow. Reduced flows may concentrate contaminants if, and when contaminants are present and increased flows may dilute contaminants. However, increased flows and pulses can mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor though deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017, Chen et al. 2018). CVP and SWP operations is not a proximate cause of contaminants mobilized from the watershed, agricultural lands, and urban effluent.

Increasing uptake of L-selenomethionine (SeMet) in juvenile green sturgeon results in an increase in mortality in fish fed 200mg SeMet/kg after only two weeks; smaller quantities of SeMet decreases feeding efficiency and reduced growth rates after four weeks (De Riu et al. 2014). Water quality monitoring has not shown contaminants at levels likely to affect juveniles and no fish effects have been observed in fish monitoring in the Delta or upper Sacramento River. Reduced flows may decrease dissolved oxygen concentrations; however, water quality monitoring has not shown dissolved oxygen at low levels in the Bay Delta or upper Sacramento River.

- The Proposed Action may increase or decrease the *food* stressor in the Sacramento River. During the juvenile rearing and outmigration period, Shasta Reservoir storage may decrease flows in the winter and spring and releases may increase flows in the summer and fall. The food stressor is not anticipated to change in the Delta because diet richness increases with total length, widening the prey selection (Zarri and Palkovacs 2018).

  Changes in water velocities in response to Sacramento River flows have been observed to change benthic macroinvertebrate community composition (Nelson and Lieberman 2002). Zarri and Palkovacs (2019) found that diet richness increases with total length in larval green sturgeon. It can be inferred that juvenile green sturgeon have increased diet richness as they increase in total length. Additionally, juvenile green sturgeon are strong enough swimmers to move into parts of the river that have wider prey availability. Once juvenile green sturgeon migrate out of the river into the estuary, their diet presumably shifts to larger benthic food items. Though available benthic food items have changed during the recent past, juvenile green sturgeon are generalists and opportunists. Mysid shrimp and amphipods (*Corophium*) were observed to be the primary food items in juvenile (<57cm) green sturgeon stomachs (Radtke 1966).

Described below are stressors exacerbated by the Proposed Action, potentially resulting in incidental take. Also described below are conservation measures included as part of the Proposed Action to avoid or compensate for adverse effects.

8.2.4.1 Entrainment Risk

The proposed diversion of water may increase the entrainment risk stressor. During the green sturgeon juvenile life stage, the proposed diversion of water alters hydrodynamic conditions in the Sacramento River and Delta. This alteration may influence fish travel time and migration routing in the Sacramento River mainstem and the central and south Delta. Once in the central and south Delta, entrainment into the Jones and Banks pumping plants may occur. Entrainment, for the purposes of this document, is defined and discussed in two ways: (1) fish routed through specific migratory pathways in the Delta (Delta route-specific travel time and survival); and (2) fish encountering CVP and SWP facilities where they may be pulled into diversions or the export facilities. Multiple topic-specific appendices address aspects of juvenile migration through the Delta. Entrainment risk is not anticipated to change in the Sacramento River, as CVP facilities located on the Sacramento River are screened.

- *Appendix G – Facility and Water Operations* including sections for *"Tracy Fish Collection Facility"* and *"Skinner Fish Delta Fish Protective Facility"*.
- Appendix I –presents analysis of "Old and Middle River Management" and "Delta Cross Channel Closure" conservation measures.
- *Appendix J – Spring Delta Outflow* presents analysis of the effects of spring Delta outflow on juvenile survival with a focus on route-specific travel time and survival.
- Appendix H – describes the "Old and Middle River Management" and "Delta Cross Channel Closure" conservation measures.

The increase in entrainment risk stressor is expected to be **lethal** or **sublethal**. Entrainment can result in direct mortality. Effects of routing fish into other areas in the Delta of poor survival (increased predation, reduced habitat quality) is unknown. It should be noted that juvenile green sturgeon larger than 20 cm total length are unlikely to be preyed upon by Largemouth Bass and Striped Bass, two highly abundant predator species in the Delta (Baird et al. 2019).

The entrainment risk stressor is influenced by thousands of non-CVP and non-SWP diversions in the rivers and Delta. Senior and junior water users would continue to operate privately-owned facilities to divert water from the Sacramento River and pose a risk of entrainment, although that risk is reduced where fish screens have been installed. The CVPIA Anadromous Fish Screen Program provides grants to screen facilities used to divert water. Diversions greater than 100 cfs are screened on the Sacramento River. Upstream from the Delta, CVP facilities on the Sacramento River are screened (e.g., Red Bluff Pumping Plant). Louver-bypass systems have been shown to be effective for larger sized juvenile green sturgeon at low velocities in a laboratory setting (Steel et al. 2022).

Reclamation's past operation of the Delta Cross Channel Gates and Reclamation and DWR's past operation of export facilities influenced the flow of water in the Delta. Reclamation and DWR have operated the CVP and SWP to reduce the risk of entrainment under biological opinions issued by the USFWS and NMFS in 2008/2009 and 2019. Under those biological opinions, Reclamation and DWR have: (1) closed the Delta Cross Channel Gates; (2) controlled the net negative flows toward the export pumps in Old and Middle rivers to reduce the likelihood that fish would be diverted from the San Joaquin or Sacramento River into the southern or central Delta; and (3) improved fish screening and salvage operations to reduce mortality from entrainment and salvage. An existing consultation proposes to install operable gates to increase fish routing into the Yolo Bypass.

The **proportion** of the population affected by the Proposed Action varies annually and depends upon flow routing, hydrology, and export rates. Literature does not uniquely inform the proportion of the population.

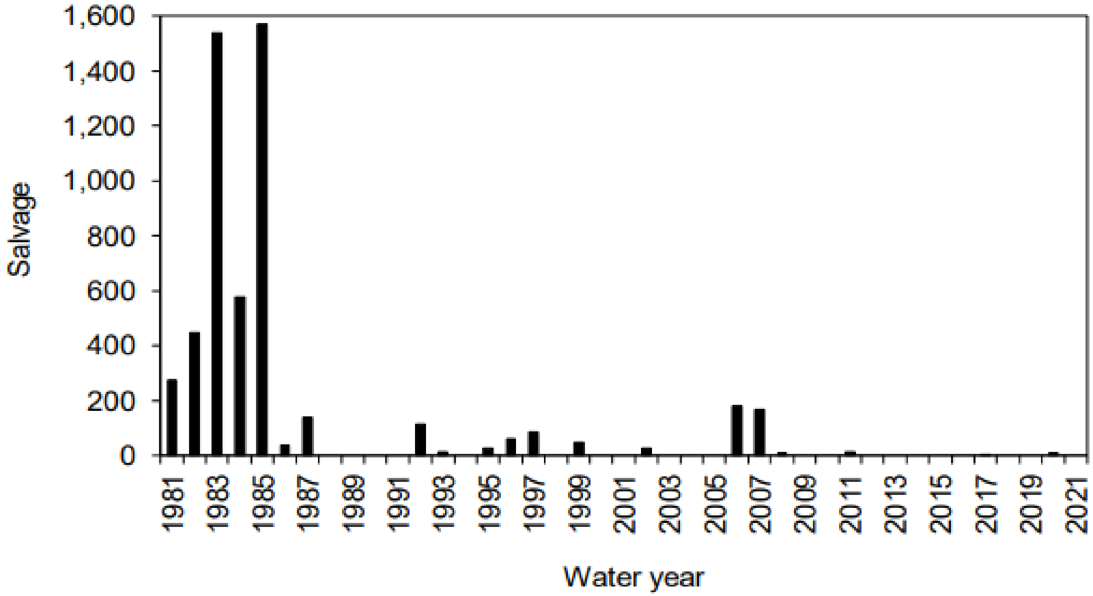
The proportion is quantified by CVP salvage data (Figure 8-9). The **proportion** of the population affected is likely **low** based on salvage data from the CVP facility prior to 2010 (1981-2009). Salvage numbers were elevated from 1981-1990, but there is no information on juvenile population estimates for this timeframe, so it is difficult to ascertain the entrained proportion of the population. The proportion of the population from 1991-2009 was likely **low**. Green sturgeon salvage in years after 2010 were more representative of current OMR management and the Proposed Action. The **proportion** of the population affected is **low** based on historic salvage records since 2010 (2010-2022). Historic records of green sturgeon encountering CVP and SWP fish collection facilities show infrequent salvage. Green sturgeon were salvaged from the facilities in three of the last 14 years.

Between 2009 and 2022, four juvenile green sturgeon were reported at the CVP fish salvage facility in the southern region of the Sacramento-San Joaquin Delta, equating to 24 salvaged green sturgeon. (Table 8-8). Since 2009, there has been a decline in green sturgeon salvage at both the CVP and SWP salvage facilities (Figure 8-9), potentially indicating protections put in place to reduce entrainment at the facilities are benefitting juvenile green sturgeon.

Table 8-8. Monthly Salvage Counts for Juvenile Green Sturgeon at the Central Valley Project Salvage Facility by Water Year.

	Month											
Water Year	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1993					12							
1995		12									12	
1996			48							12		
1997	24						12	12	24			12
1999	12	12						12				12
2002	12		12									
2006	12								12	96	24	36
2007	60	84	12	12								
2008				4			4					
2011									12			
2017									4			
2020									4	4		
Total	**120**	**108**	**72**	**16**	**12**	**0**	**16**	**24**	**56**	**112**	**36**	**60**

Data Source: https://apps.wildlife.ca.gov/Salvage/Chart/AcrefeetSalvage?Adipose=All&SampMethod=Both&orgCode=28&orgDes=Green%20Sturgeon&endDate=09%2F30%2F2022%2000%3A00%3A00&StartDate=10%2F01%2F2008%2000%3A00%3A00&ShowValue=True
Years where no salvage was recorded were left out of the table.
Water years prior to 2010 are depicted in blue.



Source: California Department of Fish and Wildlife 2022.

Figure 8-9. Annual Salvage of Green Sturgeon at the Tracy Fish Collection Facility, Water Years 1981–2021.

The Salvage Density Analysis, Appendix I, Attachment I.2 provides context for loss of green sturgeon at the export facilities. This analysis weighs south Delta exports at the export facilities by historical salvage per unit volume. Predicted annual loss of green sturgeon at the facilities under the Proposed Action phases range from zero to seven (Figure 8-10). EXP1 and EXP3 predicted loss is zero. Overall, predicted loss does not vary widely among water year types. No predicted loss occurred in Proposed Action phases for critical water year types. The highest predicted loss occurred in Proposed Action phases for wet water year types. Loss of green sturgeon at the facilities historically, including the recent past, is low. Similarly, loss under the Proposed Action is low across all water year types.

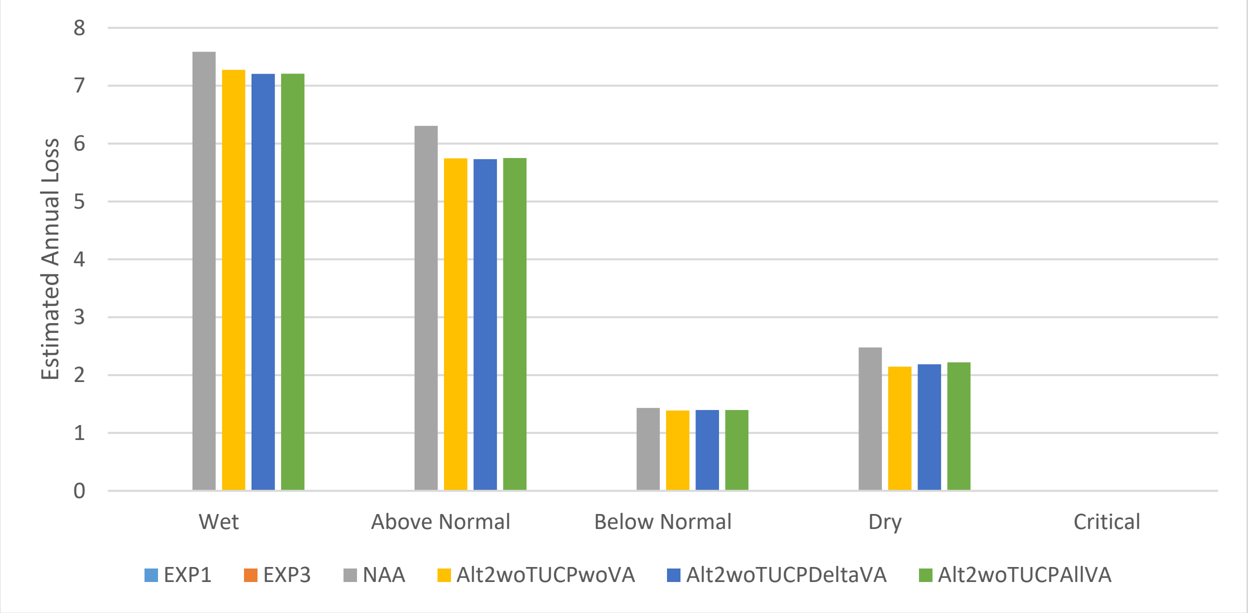


Figure 8-10. Estimated Cumulative Annual Loss of Sacramento River Origin Green Sturgeon at the Export Facilities by Water Year Type based on Salvage-Density Method.

The **frequency** of occurrence of the stressor is **high** and likely to occur annually.

Literature does not uniquely inform the frequency.

To evaluate the **weight of evidence** for the entrainment risk stressor, raw salvage data spanning water years 1981-2021 from the Tracy Fish Collection Facility was used, concentrating on water years 2011-2023, as well as the NMFS 2019 Biological Opinion.

Conservation measures in the Proposed Action that minimize or compensate for effects of the operation of the CVP and SWP on this stressor include:

- Delta Cross Channel Gate Closure
- First Flush and Start of OMR Management
- January 1 and Start of OMR Management
- End of OMR Management
- Winter and Spring Pulse and Delta Outflows
- Drought Actions
- Salvage Facilities

Conservation measures in the Proposed Action for other species, life stages and/or stressors that may exacerbate this stressor include:

- SHOT Reduction in Sacramento River Fall and Winter Flows
- Drought Actions

8.2.5 Estuarine Subadult and Adult Residence and Outmigration

Individuals between about 60-100 centimeters(cm) in total length are considered sub-adults and individuals 100 cm and larger are considered adults (Heublein et al. 2017a). The sudadult life stage is defined as first entry into the Pacific Ocean through sexual maturity. They are most commonly detected in the San Francisco, San Pablo, and Suisun Bays with occasional detections in the central and lower Sacramento River in spring months. They have been observed to spend an average of seven days in the San Francisco Bay before returning to the ocean; however, it is also hypothesized they are going in and out of the San Francisco Estuary before making their final adult migration into the Pacific Ocean. Sub-adult green sturgeon have not been detected in the upper Sacramento River (Miller et al. 2020). Post-spawning adult green sturgeon either outmigrate in the spring directly after spawning or hold in the river to outmigrate during fall and winter months. It is assumed outmigrating adults use cues of increasing flow rates to begin their migration (Israel and Klimley 2008, Colborne et al. 2022). There is no evidence of tagged adult green sturgeon exhibiting permanent residency in the Delta (Colborne et al. 2022). It is not expected that operations in the Proposed Action will affect this life stage.

8.3 Critical Habitat Analysis

Critical habitat was designated on October 9, 2009 (70 FR 52299). The geographical extent of designated critical habitat includes: coastal U.S. marine waters within 60 fathoms (fm) depth from Monterey Bay, California (including Monterey Bay), north to Cape Flattery, Washington, including the Strait of Juan de Fuca, Washington, to its United States boundary; the Sacramento River, lower Feather River, and lower Yuba River in California; the Sacramento-San Joaquin Delta and Suisun, San Pablo, and San Francisco bays in California; the lower Columbia River estuary; and certain coastal bays and estuaries in California (Humboldt Bay), Oregon (Coos Bay, Winchester Bay, Yaquina Bay, and Nehalem Bay), and Washington (Willapa Bay and Grays Harbor). This rule designates approximately 515 kilometer (km) (320 miles (mi)) of freshwater river habitat, 2,323 km^2 (897 mi^2) of estuarine habitat, 29,581 km^2 (11,421 mi^2) of marine habitat, 784 km (487 mi) of habitat in the Sacramento-San Joaquin Delta, and 350 km^2 (135 mi^2) of habitat within the Yolo and Sutter bypasses (Sacramento River, CA)

The Proposed Action area encompasses riverine and estuarine critical habitat physical and biological features for green sturgeon. Each of the features of the critical habitat designation for green sturgeon, and potential effects associated with the Proposed Action, is described in subsections below.

8.3.1 Food resources (freshwater riverine systems)

This essential physical and biological feature includes abundant prey items for larval, juvenile, subadult, and adult life stages. As identified in Section 8.2.1, *Adult Migration, River Spawning, and Holding*, there are no food related stressors that are anticipated to adversely affect adult green sturgeon.

In Section 8.2.3, *Larvae*, and Section 8.2.4, *Juvenile*, Reclamation and DWR determined that the Proposed Action may increase or decrease the *food* stressor for larvae and juvenile green sturgeon but this changes are insignificant or discountable. During the larval period, releases of Shasta Reservoir storage may increase flows in the summer. During the spring, the Proposed Action will store and divert water resulting in decreased flows. Increased flows on the Sacramento River have been observed to decrease prey taxon richness and abundance in diets of early life stage green sturgeon, especially the presence of cyclopoid copepods. Copepod abundance in the Sacramento River has been found to be inversely associated with discharge (Sommer et al. 2004). Green sturgeon larvae smaller than 30mm rely on benthic macroinvertebrates and zooplankton prey with a strong reliance on cyclopoid copepods. However, green sturgeon are also reliant on benthic macroinvertebrates through the larval life stage, including baetid mayflies (*Ephemeroptera baetidae*), chironomids (*Diptera chironomidae*), and simulids (*Diptera simuliidae*). Additionally, larval diet richness increases with total length, widening the prey selection (Zarri and Palkovacs 2018).

During the juvenile rearing and outmigration period, Shasta Reservoir storage associated with the Proposed Action may decrease flows in the winter and spring and releases may increase flows in the summer and fall. Changes in water velocities in response to Sacramento River flows have been observed to change benthic macroinvertebrate community composition (Nelson and Lieberman 2002). Zarri and Palkovacs (2019) found that diet richness increases with total length in larval green sturgeon. It can be inferred that juvenile green sturgeon have increased diet richness as they increase in total length. Additionally, juvenile green sturgeon are strong enough swimmers to move into parts of the river that have wider prey availability.

8.3.2 Substrate type or size (i.e., structural features of substrates) (freshwater riverine systems)

This essential physical and biological feature includes substrates suitable for egg deposition and development (e.g., bedrock sills and shelves, cobble and gravel, or hard clean sand, with interstices or irregular surfaces to “collect” eggs and provide protection from predators, and free of excessive silt and debris that could smother eggs during incubation), larval development (e.g., substrates with interstices or voids providing refuge from predators and from high flow conditions), and feeding of juveniles, subadults, and adults (e.g., sand/mud substrates).

As identified in section 8.2.2, *Egg Incubation*, the Proposed Action increase or decrease in the *incubation habitat* stressor is insignificant or discountable . During the egg incubation period, the Proposed Action will store and divert water in the spring and decrease flows in the Sacramento River below Keswick Dam. During the summer, the Proposed Action will release water and increase flows in the Sacramento River between Keswick Dam and Bend Bridge.

Decreased flows may be occasionally low near Keswick Dam to maintain winter-run Chinook salmon habitat quality, although green sturgeon have only been documented to spawn as far north as the confluence with Cow Creek, south of Clear Creek. Increased flows in the summer may provide environmental conditions favorable to eggs and developing embryos for green sturgeon. Flows between 269-396 cubic meters per second are sufficient to maintain clean gravel and reduce the risk of suffocation by sand deposition (Poytress et al. 2015). The Proposed Action results in flows within this range.

8.3.3 Water flow (freshwater riverine systems)

This essential physical and biological feature includes a flow regime (i.e., the magnitude, frequency, duration, seasonality, and rate-of-change of fresh water discharge over time) necessary for normal behavior, growth, and survival of all life stages.

As identified in Section 8.2.1, *Adult Migration, River Spawning and Holding*, Section 8.2.3, *Larvae*, and Section 8.2.4, *Juveniles*, the Proposed Action may increase or decrease the *flow* stressor.

During the adult migration, spawning, and holding period, the Proposed Action will store and divert water in the winter resulting in decreased flows. In the summer, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Increased flows in the Sacramento River during the summer could affect adult holding and cue riverine outmigration. River discharge is hypothesized to cue “late” outmigrating adult green sturgeon in the winter, meaning lower minimum daily flows in the winter could impact the duration of post spawning holding or timing of adult outmigration. However, adult green sturgeon have been observed in the Sacramento River year round, with some individuals holding in the river for over a year. This behavior indicates the species’ ability to change outmigration strategies based on river discharge patterns (Colborne et al. 2022). If flows decrease in the winter, green sturgeon may hold until the following year or be cued based on precipitation rather than managed flows. If flows increase during the summer it may cue sturgeon to outmigrate. It is likely green sturgeon adjust their holding times based on minimum discharge rates regardless of season (Colborne et al. 2022).

During the larval period, the Proposed Action will store and divert water in the spring and decrease flows. During the summer, the Proposed Action will release water and increase flows. Body condition in larval green sturgeon is negatively correlated with increased discharge (Zarri et al. 2019). However, flow at the Red Bluff Diversion Dam has been positively correlated with larval abundance (Heublein et al. 2017b). It has been observed that larval green sturgeon can benefit from reduced flows and increased flows. Information on flow and requirements for rearing green sturgeon larvae is limited and not well understood.

During the spring, the proposed storage under the Proposed Action in Shasta Reservoir may decrease flows, thereby increasing water temperatures. Juvenile green sturgeon growth may increase with increased water temperatures and decreased flows. On the other hand, increased releases of Shasta Reservoir storage may decrease water temperatures in the summer, and juvenile growth may decrease with lower temperatures and increased flows (Zarri et al. 2019). The combination of higher discharge and lower temperatures appears to reduce larval sturgeon body condition (Zarri et al. 2019) and may similarly impact juveniles during the summer months. However, rapid growth generally occurs in the juvenile life stage (Heublein et al. 2017a), and juvenile green sturgeon are strong enough swimmers to move to acceptable habitat.

8.3.4 Water quality (freshwater riverine systems)

This essential physical and biological feature includes temperature, salinity, oxygen content, and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages related to water quality.

As identified in section the Proposed Action may increase or decrease the *toxicity* stressor, but this change is insignificant and discountable. The Proposed Action is not anticipated to change the *dissolved oxygen* stressor (8.2.1, *Adult Migration, River Spawning, and Holding*, and Appendix D). During the adult migration, spawning, and holding period, the Proposed Action will store and divert water in the winter and spring and decrease flows. In the summer and fall, the Proposed Action will release water and increase flows in the Sacramento River below Keswick Dam. Reduced flows may concentrate contaminants if, and when contaminants are present and increased flows may dilute contaminants. Increased flows and pulses may mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). CVP and SWP operations are not a proximate cause of contaminants mobilized from the watershed, agricultural lands, and urban effluent.

Dissolved oxygen less than 5.0mg/L may affect migration of other large bodied anadromous fishes (Carter 2005). Reclamation's water quality monitoring have not shown dissolved oxygen at levels below this in the winter, spring, summer, or fall in the Sacramento River.

The *salinity* stressor is not anticipated to change in the Sacramento River because green sturgeon present in the Sacramento River upstream of the Bay-Delta would not be anticipated to experience high salinity concentrations.

As identified in section 8.2.2, *Egg Incubation*, the Proposed Action may increase or decrease the *toxicity and dissolved oxygen* stressor. These changes are expected to be insignificant or discountable. During the egg incubation period, the Proposed Action will store and divert water in the spring and decrease flows in the Sacramento River below Keswick Dam. During the summer, the Proposed Action will release water and increase flows in the Sacramento River between Keswick Dam and Bend Bridge. Reduced flows may concentrate contaminants if and when contaminants are present and increased flows may dilute contaminants. Increased flows and pulses may mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). Water quality monitoring in the upper Sacramento River has not shown contaminants or dissolved oxygen at levels likely to affect eggs and no fish effects have been observed in Red Bluff Diversion Dam fish monitoring, where juvenile green sturgeon are annually observed. During incubation, the embryos obtain nutrition from the yolk sac, which reduces their exposure to contaminants in prey during this life stage.

As identified in section 8.2.4, *Larvae*, the Proposed Action may increase the *toxicity and dissolved oxygen* stressor in an insignificant or discountable manner. During the larval period, the storage of water associated with the Proposed Action will decrease flows in the Sacramento River below Keswick Dam. Reduced flows may concentrate contaminants and decrease dissolved oxygen concentrations. Water quality monitoring has not shown contaminants at levels likely to affect larvae and no fish effects have been observed in fish monitoring. Water quality monitoring has not shown dissolved oxygen at low levels in the spring and summer.

As identified in 8.2.4, *Juveniles*, the Proposed Action may increase the *toxicity and dissolved oxygen* stressor in an insignificant or discountable manner. During the juvenile rearing and outmigration period, the Proposed Action storage and diversion of water decreases flow in the Sacramento River. Reduced flows may concentrate contaminants if, and when contaminants are present. Water quality monitoring has not shown contaminants at levels likely to affect juveniles and no fish effects have been observed in fish monitoring in the upper Sacramento River.

Reduced flows may decrease dissolved oxygen concentrations; however, water quality monitoring has not shown dissolved oxygen at low levels in the upper Sacramento River.

8.3.5 Migratory corridor (freshwater riverine systems)

This essential physical and biological feature includes a migratory pathway necessary for the safe and timely passage of all life stages within riverine habitats and between riverine and estuarine habitats (e.g., an unobstructed river or dammed river that still allows for safe and timely passage).

As identified in Section 8.2.1. *Adult Migration, River Spawning, and Holding*, there are no *barrier* related stressors that are anticipated to adversely affect green sturgeon migratory corridors.

8.3.6 Depth (freshwater riverine systems)

This essential physical and biological feature includes deep (≥ 5 m) holding pools for both upstream and downstream holding of adult or subadult fish, with adequate water quality and flow to maintain the physiological needs of the holding adult or subadult fish.

As identified in Section 8.2.1, *Adult Migration, River Spawning, and Holding*, there are no *spawning habitat* related stressors that are anticipated to adversely affect holding adult or subadult green sturgeon.

8.3.7 Sediment quality (freshwater riverine systems)

This essential physical and biological feature includes sediment quality (i.e., chemical characteristics) necessary for normal behavior, growth, and viability of all life stages.

As identified in Section 8.2.1, *Adult Migration, River Spawning, and Holding*, there are no *spawning habitat* related stressors that are anticipated to adversely affect holding adult green sturgeon.

As identified in Section 8.2.2, *Egg Incubation*, the Proposed Action may increase or decrease the *incubation habitat* stressor in an insignificant or discountable manner. During the egg incubation period, the Proposed Action will store and divert water in the spring and decrease flows in the Sacramento River below Keswick Dam. During the summer, the Proposed Action will release water and increase flows in the Sacramento River between Keswick Dam and Bend Bridge.

Decreased flows may be occasionally low near Keswick Dam to maintain winter-run Chinook salmon habitat quality, although green sturgeon have only been documented to spawn as far north as the confluence with Cow Creek, south of Clear Creek. Increased flows in the summer may provide environmental conditions favorable to eggs and developing embryos. Flows between 269-396 cubic meters per second are sufficient to maintain clean gravel and reduce the risk of suffocation by sand deposition (Poytress et al. 2015). The Proposed Action results in flows within this range.

8.3.8 Food resources (estuarine habitats)

This essential physical and biological feature includes abundant prey items within estuarine habitats and substrates for juvenile, subadult, and adult life stages.

As identified in Sections 8.2.1, *Adult Migration, River Spawning, and Holding*, and 8.2.4, *Juveniles*, the Proposed Action is not anticipated to materially change the food stressor for green sturgeon in the Delta.

8.3.9 Water flow (estuarine habitats)

Within bays and estuaries adjacent to the Sacramento River (i.e., the Sacramento-San Joaquin Delta and the Suisun, San Pablo, and San Francisco bays), sufficient flow into the bay and estuary to allow adults to successfully orient to the incoming flow and migrate upstream to spawning grounds.

As identified in Section 8.2.1, *Adult Migration, River Spawning and Holding*, *flow* is not identified as a stressor for adult green sturgeon within the Delta based on the green sturgeon SAIL model and it’s hypothesized stressors, summarized from Heublein et al. 2017a.

As identified in Section 8.2.4, *Juveniles*, the Proposed Action may increase or decrease the *flow* stressor. During the juvenile rearing and outmigration period, the Proposed Action will decrease Delta outflow due to downstream storage and diversions.

Although decreased outflow and increased diversions may change the duration of juvenile residency, juvenile green sturgeon may occupy brackish and freshwater habitats in the Delta for up to one and a half years until they can tolerate seawater (Allen 2005, Poletto et al. 2013). Juveniles may remain in the Delta for up to three years based on capture of fish of this age in fish monitoring surveys and salvage. The long Delta residency of green sturgeon juveniles is unlikely to be influenced by seasonal changes in delta flows.

8.3.10 Water quality (estuarine habitats)

This essential physical and biological feature includes temperature, salinity, oxygen content, and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages related to water quality.

As identified in Section 8.2.1, *Adult Migration, River Spawning, and Holding*, the Proposed Action may increase the *toxicity* stressor in the Delta in an insignificant or discountable manner and is not anticipated to change the *dissolved oxygen* stressor. CVP and SWP storage and diversion of water decreases Delta inflow and outflow limiting the potential for dilution of contaminants; however, CVP and SWP operations is not a proximate cause of contaminants mobilized from the watershed, agricultural lands, and urban effluent. Adult green sturgeon do not spend a substantial portion of their life foraging in the Bay-Delta (Heublein et al. 2017a).

As described in Section 8.2.4, *Juveniles*, the Proposed Action may increase the *toxicity* and *dissolved oxygen* stressor. During the juvenile rearing and outmigration period, CVP and SWP storage and diversion of water decreases flow in the Sacramento River, inflow into the Delta, and Delta outflow. Reduced flows may concentrate contaminants if, and when contaminants are present and increased flows may dilute contaminants. However, increased flows and pulses can mobilize suspended sediments consisting of contaminants in river systems (van Vliet et al. 2023). The timing of snowmelt may also play a role in this stressor though deposited pollutants in dust though studies on contaminants present in snowmelt and rainfall runoff have reported differing results (Parajulee et al. 2017, Chen et al. 2018). CVP and SWP operations is not a proximate cause of contaminants mobilized from the watershed, agricultural lands, and urban effluent. For juvenile green sturgeon, increasing uptake of L-selenomethionine (SeMet) results in an increase in mortality in fish fed 200mg SeMet/kg after only two weeks; smaller quantities of SeMet decreases feeding efficiency and reduced growth rates after four weeks (De Riu et al. 2014). Water quality monitoring has not shown contaminants at levels likely to affect juveniles and no fish effects have been observed in fish monitoring in the Delta. Reduced flows may decrease dissolved oxygen concentrations; however, water quality monitoring has not shown dissolved oxygen at low levels in the Bay Delta.

As identified in Section 8.2.4, *Juveniles*, the Proposed Action may increase or decrease the *water temperature* stressor in an insignificant or discountable manner. During the juvenile outmigration and rearing period, CVP and SWP storage and diversion may increase or decrease Delta inflow. Delta water temperature is negatively correlated with Delta inflow in the spring (Bashevkin and Mahardja 2022) and reservoir operations may influence water temperature to a minimal extent in the lower reaches of the Sacramento River (Daniels and Danner 2020). Additionally, CVP and SWP storage and diversion of water decrease inflow in November, while summer seasonal operations increase Delta inflow. In the Delta water temperature is mainly driven by timing of snowmelt (Knowles and Cayan 2002), air temperature and meteorology (Vroom et al. 2017, Daniels and Danner 2020). There is uncertainty about whether changes in Delta inflow is a cause for changes in Delta water temperatures.

Dissolved oxygen less than 5.0mg/L may affect migration of other large bodied anadromous fishes (Carter 2005). Reclamation’s water quality monitoring have not shown dissolved oxygen at levels below this in the winter, spring, summer, or fall in the Bay Delta.

The Proposed Action may increase or decrease the *salinity* stressor in the Delta. Increased inflows in September and October and decreased inflows in November, winter months, and spring months may alter the amount of brackish habitat in the Delta. Adult Green Sturgeon are hypothesized to use a broad range of habitats and water quality conditions. A telemetry study in the Delta detected green sturgeon at salinities between 8.8-32.1 ppt, with no specific salinity preferences (Kelly et al. 2007).It is hypothesized that changes in salinity may influence the distribution of juvenile green sturgeon (Heublein et al. 2017a). Juveniles were found to display a preference for seawater (Poletto et al. 2013). While exposure of young juveniles (<170 dph) to brackish water can negatively impact growth and survival, growth effects occur at salinities > 10 ppt, and survival effects occur at 20-30 ppt (Allen et al. 2011, Allen and Cech, 2007). Juvenile green sturgeon have a broad tolerance for salinity and are strong enough swimmers to move to acceptable habitat.

8.3.11 Migratory corridor (estuarine habitats)

This essential physical and biological feature includes a migratory pathway necessary for the safe and timely passage of all life stages within estuarine habitats and between estuarine and riverine or marine habitats.

As identified in Section 8.2.1. *Adult Migration, River Spawning, and Holding*, there are no barrier related stressors exacerbated by the Proposed Action that are anticipated to negatively affect green sturgeon migratory corridors.

8.3.12 Depth (estuarine habitats)

This essential physical and biological feature includes a diversity of depths necessary for shelter, foraging, and migration of juvenile, subadult, and adult life stages.

As identified in Section 8.2.1. *Adult Migration, River Spawning, and Holding*, there are no stressors exacerbated by the Proposed Action that are anticipated to negatively affect depth related to the foraging and migration of juvenile, subadult, and adult green sturgeon.

8.3.13 Sediment quality (estuarine habitats)

This essential physical and biological feature includes sediment quality (i.e., chemical characteristics) necessary for normal behavior, growth, and viability of all life stages. The Proposed Action is not expected to materially affect sediment quality in the Delta.

8.3.14 Migratory corridor (nearshore coastal marine areas)

This essential physical and biological feature includes a migratory pathway necessary for the safe and timely passage of all life stages within marine and between estuarine and marine habitats. As identified in Section 8.2.5, *Estuarine Subadult and Adult Residence and Outmigration*, there are no stressors exacerbated by the Proposed Action in nearshore coastal marine areas.

8.3.15 Water quality (nearshore coastal marine areas)

This essential physical and biological feature includes nearshore marine waters with adequate dissolved oxygen levels and low enough levels of contaminants (e.g., pesticides, organochlorines, elevated levels of heavy metals) to allow normal behavior, growth, and viability of subadult and adult green sturgeon.

As identified in Section 8.2.5, *Estuarine Subadult and Adult Residence and Outmigration*, there are no stressors exacerbated by the Proposed Action in nearshore coastal marine areas.

8.3.16 Food resources (nearshore coastal marine areas)

This essential physical and biological feature includes abundant prey items for subadults and adults, which may include benthic invertebrate fishes.

As identified in Section 8.2.5, *Estuarine Subadult and Adult Residence and Outmigration*, there are no stressors exacerbated by the Proposed Action in near coastal marine areas

8.4 Lifecycle Analysis

Increased Delta outflow is associated with increased year-class strength as demonstrated in Table 8-9 and Table 8-10. White sturgeon are used as a surrogate for green sturgeon.

Table 8-9. Year-Class Strength of Green Sturgeon Based on April–May Regression with Delta Outflow.

WYT	**EXP 1**	**EXP 3**	**NAA**	**Alt2woTUCP woVA**	**Alt2woTUCP DeltaVA**	**Alt2woTUCP AllVA**
W	139.1	58.2	30.3	29.0	29.5	29.7
AN	16.9	8.5	5.8	5.2	5.4	6.0
BN	8.8	4.7	3.5	3.3	3.4	3.8
D	3.4	2.3	2.2	2.2	2.2	2.4
C	1.7	1.6	1.4	1.5	1.6	1.7
All	46.6	20.2	11.2	10.7	10.9	11.2

Table only includes annual mean responses and does not consider model uncertainty.
WYT = Water Year Type, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, C= Critically Dry.

The average Year-Class Strength indexes (YCI) by water year type based on the April-May regression with Delta-Outflow are presented in Table 8-9. The average overall YCI values are generally similar across all the Proposed Action phases, with the highest average values obtained for the Proposed Action Without TUCP Systemwide VA component at 11.2 and the lowest average values obtained for Proposed Action Without TUCP Without VA at 10.7. This pattern would hold true across water year types with ranges (min-max) of average YCI going from 0.3 in Critically Dry years to 1.3 in Wet years. In Critically Dry years, the lowest average YCI would be obtained for the Proposed Action Without TUCP Without VA (1.5) and the highest for Proposed Action Without TUCP Systemwide VA (1.7). In Dry years, the average YCI would be very consistent across all Proposed Action phases; Proposed Action Without TUCP Systemwide VA at 2.4 and all others at 2.2. In Below Normal years, the lowest average YCI would be obtained for Proposed Action Without TUCP Without VA (3.3) and the highest for PA Without TUCP Systemwide VA (3.8). In Above Normal years, the lowest average YCI would be obtained for PA Without TUCP Without VA (5.2) and the highest for PA Without TUCP Systemwide VA (6). In Wet years, the lowest average YCI would be obtained for Proposed Action Without TUCP Without VA (29) and the highest for the Proposed Action Without TUCP All VA (29.7).

Table 8-10. Year-Class Strength of Green Sturgeon Based on March–July Regression with Delta Outflow.

WYT	EXP 1	EXP 3	NAA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA
W	159.6	90.0	48.9	47.9	48.3	48.3
AN	14.5	9.9	6.7	6.3	6.5	6.9
BN	5.5	3.8	2.9	2.8	2.9	3.1
D	2.8	2.3	2.0	1.9	2.0	2.1
C	1.4	1.4	1.2	1.2	1.3	1.4
All	51.7	29.7	16.7	16.3	16.6	16.7

Table only includes annual mean responses and does not consider model uncertainty.
WYT = Water Year Type, W = Wet, AN = Above Normal, BN = Below Normal, D = Dry, C= Critically Dry.

The average Year-Class Strength indexes (YCI) by water year type based on the March-July regression with Delta-Outflow are presented in Table 8-10. The average overall YCI values would generally be similar across all Proposed Action phases, with the highest average values obtained for the Proposed Action Without TUCP Systemwide VA at 16.7 and the lowest average values obtained for Proposed Action Without TUCP Without VA at 16.3. This pattern would hold true across water year types with ranges (min-max) of average YCI going from 0.2 in Critically Dry years to 1 in Wet years. In Critically Dry years, the lowest average YCI would be obtained for the Proposed Action Without TUCP Without VA (1.2) and the highest for PA Without TUCP Systemwide VA (1.4). In Dry years, the lowest average YCI would be obtained for Proposed Action Without TUCP Without VA (1.9) and the highest for Proposed Action Without TUCP Systemwide VA (2.1). In Below Normal years, the lowest average YCI would be obtained for Proposed Action Without TUCP Without VA (2.8) and the highest for Proposed Action Without TUCP Systemwide VA (3.1). In Above Normal years, the lowest average YCI would be obtained for Proposed Action Without TUCP Without VA (6.3) and the highest for Proposed Action Without TUCP Systemwide VA (6.9). In Wet years, the lowest average YCI would be obtained for Proposed Action Without TUCP Without VA (47.9) and the highest for the Proposed Action Without TUCP Delta VA and PA Without TUCP Systemwide VA (48.3).

8.5 References

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8.5.1 Personal Communication

Poytress, W., Program Manager, Red Bluff Fish and Wildlife Office, Email communication to Josh Israel, Chief, Science Division, U.S. Bureau of Reclamation, Bay-Delta Office and Kristin Arend, Fish Biologist, U.S. Bureau of Reclamation, Bay-Delta Office, regarding egg, larval, and juvenile green sturgeon presence at Red Bluff Diversion Dam and middle Sacramento River. December 27, 2021.