Southern Distinct Population Segment of North American Green Sturgeon
(Acipenser medirostris)

5-Year Review:
Summary and Evaluation

National Marine Fisheries Service
California Central Valley Office
Sacramento, California

5-YEAR REVIEW

Species reviewed: Southern Distinct Population Segment of the North American Green Sturgeon (*Acipenser medirostris*)

TABLE OF CONTENTS

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1.0 GENERAL INFORMATION

1.1 Reviewers

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1.2 Methodology used to complete review

The 5-year review was conducted by the NOAA NMFS West Coast Region's California Central Valley Office, in collaboration with personnel at other NOAA NMFS West Coast Region offices (California Coastal Office, Long Beach Office, Interior Columbia Basin Office, and Lacey Office). The review process included collecting information through the following: (1) a literature search for information published since the last review (2015); (2) publication of a Federal Register (FR) notice soliciting new information about the Southern Distinct Population Segment (DPS) of North American green sturgeon (85 FR 12905; March 5, 2020); and (3) email and phone contact with knowledgeable individuals at universities, tribal agencies, and state and federal government agencies. Overall, the best available scientific information was used to evaluate if the biological status and the Endangered Species Act (ESA) listing factors have changed over the last 5 years.

1.3 Background

1.3.1 FR Notice citation announcing initiation of this review

A Federal Register notice (85 FR 12905, March 5, 2020) announced the initiation of this review.

1.3.2 Listing History

<u>Original Listing</u>
FR notice: 71 FR 17757
Date listed: April 7, 2006
Entity listed: Southern Distinct Population Segment (DPS) of North American green sturgeon
Classification: Threatened

1.3.3 Associated rulemakings

Critical Habitat: On Oct. 9, 2009, NMFS designated critical habitat for the Southern DPS of North American green sturgeon (74 FR 52300).

ESA 4(d) rule: On June 2, 2010, NMFS published final Endangered Species Act protective regulations (ESA 4(d) rule) for the Southern DPS of North American green sturgeon (75 FR 30714).

1.3.4 Review History

Status Review: In 2002, a status review was conducted by a Biological Review Team (BRT) in response to a 2001 petition to list North American green sturgeon under the Endangered Species Act (Adams et al. 2002). The BRT identified the Northern and Southern DPS structure that is currently applied and concluded that green sturgeon in both DPSs should be placed on the Species of Concern list (then the Candidate species list) and their status reviewed within five years (Adams et al. 2002). In 2005, NMFS' Southwest and Northwest Fisheries Science Centers updated the Status Review as a result of a 2004 court ruling remanding to NMFS for further consideration of whether green sturgeon are endangered or threatened in a "significant portion of the species' range" (BRT 2005). The BRT updated the review and concluded that the Northern DPS was not in danger of extinction now or likely to become endangered in the foreseeable future throughout all of its range. All but one member of the BRT concluded that green sturgeon in the Southern DPS were likely to become endangered in the foreseeable future throughout all of its range.

On April 7, 2006, NMFS published notification of the listing of the Southern DPS of North American green sturgeon as Threatened (71 FR 17757). The DPS structure for North American green sturgeon was originally defined as follows: (1) a Northern DPS consisting of populations in coastal watersheds northward of and including the Eel River (''Northern DPS''); and (2) a Southern DPS consisting of coastal and Central Valley populations south of the Eel River, with the only known spawning population in the Sacramento River (''Southern DPS'') (71 FR 17757; April 7, 2006). The definition was slightly revised for accuracy with the announcement of critical habitat as follows: (1) a Northern DPS consisting of populations originating from coastal watersheds northward of and including the Eel River (i.e., the Klamath and Rogue rivers) ("Northern DPS"); and (2) a Southern DPS consisting of populations originating from coastal watersheds south of the Eel River, with the only known spawning population in the Sacramento River ("Southern DPS") (74 FR 52300; Oct. 9, 2009). In the April 7, 2006 listing notification (71 FR 17757), the Northern DPS was identified as a NMFS Species of Concern but was not listed under the ESA. NMFS stated that it would revisit the status of both DPSs' in five years' time. The 2015 5-year review focused only on the status of the Southern DPS. The Northern DPS status was the focus of a separate informal report that was been added to the 2015 record. The 2015 review determined that there was no change in listing and that the Southern DPS will remain Threatened. The 2018 Recovery Plan for the Southern DPS of the North American Green Sturgeon provided demographic criteria for recovery and ranking of threats by listing factor, life stage, and habitat type (NMFS 2018). This 5-year status review focuses only on the status of the Southern DPS.

1.3.5 Species' Recovery Priority Number at start of 5-year review

The recovery priority number for the Southern DPS green sturgeon is 6C, as reported in the NMFS Recovering Threatened and Endangered Species FY 2017-2018 Report to Congress (available at www.fisheries.noaa.gov/feature-story/recovering-threatened-and-endangered-species-report-congress-2017-2018). A Recovery Priority Number of 6C indicates a moderate magnitude of threat in some regions, a high recovery potential in many regions, and the presence of conflict with economic and resource use interests.

1.3.6 Recovery Plan or Outline

Name of plan or outline: Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon (*Acipenser medirostris*)
Date issued: August 8, 2018
Dates of previous revisions, if applicable: N/A

2.0 REVIEW ANALYSIS

2.1 Application of the 1996 Distinct Population Segment (DPS) policy

2.1.1 Is the species under review a vertebrate?

Yes.

2.1.2 Is the species under review listed as a DPS?

Yes.

2.1.3 Was the DPS listed prior to 1996?

No.

2.1.4 Is there relevant new information for this species regarding the application of the DPS policy?

Yes, studies published since 2015 further confirm the DPS structure of North American green sturgeon as defined in Section 1.3.4 of this review. These new studies are covered in Sections 2.3.1.3 and 2.3.1.5 of this review. As discussed in the previous review, Israel et al. (2009) upholds the Northern and Southern DPS determination of spawning rivers. Telemetry studies and unpublished data also confirm the DPS structure (Lindley et al. 2008, Lindley et al. 2011). Spawning of Southern DPS green sturgeon was confirmed in Sacramento River tributaries, the Feather and Yuba rivers during years with higher flow (Seesholtz et al. 2015, Beccio 2018, 2019). Green sturgeon spawning was documented in the Eel River, and all genetic samples represented the Northern DPS (Stillwater Sciences and Wiyot Tribe Natural Resources 2017). Schreier et al. (2016) examined size differences between Northern and Southern DPS holding in the Columbia River estuary, Willapa Bay, and Grays Harbor, with Northern DPS being significantly smaller than Southern DPS. Green sturgeon concentrating in the Columbia River estuary and Willapa Bay were primarily Southern DPS, while green sturgeon in Grays Harbor were represented equally among the DPSs (Schreier et al. 2016). The population found within the Gulf of Farallones were primarily Southern DPS, while the population found in the plume of the Columbia River were primarily Northern DPS (Anderson et al. 2017). A genetically confirmed green sturgeon was observed holding in a pool in the Stanislaus River near Knights Ferry, California (Anderson et al. 2018). In April 2020, a confirmed green sturgeon was observed in the San Joaquin River near the mouth of the Merced River (Root et al. 2020).

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?

Yes.

2.2.2 Adequacy of recovery criteria

2.2.2.1 Do the recovery criteria reflect the best available and most up-to-date information on the biology of the species and its habitat?

Yes.

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)?

Yes.

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information.

The recovery criteria are organized according to: (1) Demographic Recovery Criteria addressing abundance, distribution, productivity, and diversity; and (2) Threat-Based Recovery Criteria addressing the significant known threats impeding recovery.

Demographic Recovery Criteria:

1. The adult Southern DPS green sturgeon census population remains at or above 3,000 for 3 generations (this equates to a yearly running average of at least 813 spawners for approximately 66 years). In addition, the effective population size must be at least 500 individuals in any given year and each annual spawning run must comprise a combined total, from all spawning locations, of at least 500 adult fish in any given year.
   a. *Criteria Not Met:* The estimated total population of Southern DPS green sturgeon is 17,548 individuals, with an estimated 2,106 adults (Mora et al.

2018). The adult population does not met the criteria of a yearly average 3,000 adults. Reported spawner counts have been less than 500 in the Sacramento River (Mora et al. 2018, Peter Dudley, SWFSC pers. comm. September 28, 2020). Currently, there are no reliable estimates for spawner counts for the Feather and Yuba rivers.

2. Southern DPS green sturgeon spawn successfully in at least two rivers within their historical range. Successful spawning will be determined by the annual presence of larvae for at least 20 years.
   a. *Criteria Not Met:* Although spawning has been reported in the Feather and Yuba rivers, continuous spawning in these rivers has not been observed (Seesholtz et al. 2015, Beccio, 2018, 2019). Continuous spawning has been reported in the Sacramento River since 1995 (Poytress et al. 2015, Poytress 2020).
3. A net positive trend in juvenile and subadult abundance is observed over the course of at least 20 years.
   a. *Criteria Not Met:* Although juvenile monitoring for Southern DPS green sturgeon is occurring, it does not currently inform population indices (Beccio 2020).
4. The population is characterized by a broad distribution of size classes representing multiple cohorts that are stable over the long term (20 years or more).
   a. *Criteria Not Met:* Beamesderfer et al. (2007) estimated that adult, subadult, and juvenile green sturgeon in a hypothetical population at equilibrium would comprise 12%, 63%, and 25% of the population, respectively. These values are the best available information to date and can serve as a guideline for evaluating population equilibrium in the Southern DPS green sturgeon. However, further modeling may identify different benchmarks for measuring population equilibrium, and a larger percentage of younger fish may be present in the Southern DPS in the early stages of potential recovery. Further research needs to be done to inform this criterion.
5. There is no net loss of Southern DPS green sturgeon diversity from current levels.
   a. *Criteria Not Met:* Spawning habitat was used as a proxy for diversity because diversity is closely tied with abundance, distribution, and productivity. Since the previous review, spawning habitat available to Southern DPS has not increased.

Threat-Based Recovery Criteria

A. Present or Threatened Destruction, Modification, or Curtailment of a Species Habitat or Range
    a. Access to spawning habitat is improved through barrier removal or modification in the Sacramento, Feather, and/or Yuba rivers such that successful spawning occurs annually in at least two rivers.

Successful spawning will be determined by the annual presence of larvae for at least 20 years.

i. *Criteria Not Met:* Barriers to migration caused by impoundments continue to be a very high threat to green sturgeon recovery. Although access to spawning habitat was improved with the decommissioning of Red Bluff Diversion Dam (RBDD) in 2012, more needs to be done such as volitional fish passage above spawning barriers at Sunset Pumps rock weir on the Feather River and Daguerre Point Dam on the Yuba River. Threats identified at listing and during recovery plan development include: reduction of spawning areas (i.e., barriers), screened and unscreened water diversions, flow, temperature, and contaminants. Channel control structures, impoundments, and non-native species competitions altering prey base are very high threats.

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

   i. *Criteria Not Met*: Volitional passage for adult green sturgeon has been addressed at Yolo Bypass but further passage projects at Yolo and Sutter bypasses need to be completed (e.g., Fremont Weir Adult Fish Passage, Tisdale Weir improvements, Sacramento Bypass Fish Passage). Water diversions remain a medium threat.

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

   i. *Criteria Not Met:* Water temperature and flow targets have not been developed for green sturgeon. Water temperature and flow remain a medium threat and remain a high priority for research and development.

d. Adult contaminant levels are below levels that are identified as limited population maintenance and growth

   i. *Criteria Not Met*: Additional research focusing on contaminant impacts on green sturgeon life history is needed. The impacts of contaminants remain a medium threat and a high priority for research and development.

B. Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

a. Take of adults and subadults through poaching and state, federal and tribal fisheries is minimal and does not limit population persistence and growth.
    i. *Criteria Not Met*: Any take of subadult or adult Southern DPS green sturgeon may limit population productivity. Further research is needed to determine the mortality estimates of poaching and fisheries bycatch. Fishery Management and Evaluation Plans (FMEP) are needed by each state to demonstrate the impact of unintentional death related to fisheries. Overutilization for scientific research and poaching remain a high and moderate threat, respectively. Retention of North American green sturgeon is not currently permitted in any state fishery. The California Department of Fish and Wildlife (CDFW), Washington Department of Fish and Wildlife (WDFW), and Oregon Department of Fish and Wildlife (ODFW) all prohibit the commercial retention and sale of green sturgeon.

C. Disease and Predation
  a. No threat-based criteria were developed for this category.
    i. Disease and predation associated with water quality, native and non-native species, and marine mammals remain a high threat. The extent of the potential threat from disease and predation in terms of limiting population growth and recovery remain an area where further research is needed.

D. Inadequacy of Existing Regulatory Mechanisms
  a. No threat-based criteria were developed for this category.
    i. Fishing regulations were considered a high threat at listing; however, regulations were put in place (Recreational: 2006 in California, 2007 in Columbia River and Washington, and 2010 in Oregon; Commercial: 1917 in California, 2006 in Columbia River and Washington, and 2010 in Oregon) prohibiting the take of North American green sturgeon. Derelict fishing gear may pose a risk to green sturgeon. Continued improvements are needed to regulatory mechanisms associated with the following factors: (1) sturgeon passage improvements at critical locations (e.g., rock weir at Sunset Pumps, Daguerre Point Dam); (2) modification of impoundment operations or facilities to address flow, water temperature, and sediment impacts (e.g., Oroville-Thermalito Complex); (3) improvements of lock and gate operations at the Port of Sacramento and Delta Cross Channel; (4) enforcement of poaching and other fishery regulations such as bycatch in state fisheries; (5)

screening criteria and regulation for agriculture, municipalities, and industrial water diversions; (6) land use regulations for non-point and point source contaminants; (7) control of invasive species (e.g., overbite clams); (8) response plans for oil and chemical spills; and (9) permitting of offshore and nearshore kinetic energy projects. Criteria for screening and fish passage for green sturgeon has yet to be developed. These criteria are needed to prevent entrainment of juvenile green sturgeon at water diversions. Once developed, these criteria should be implemented throughout Southern DPS green sturgeon critical habitat.

E. Other Natural or Manmade Factors Affecting Its Continued Existence
   a. Operation guidelines and/or fish screens are applied to water diversions in mainstem Sacramento, Feather, and Yuba rivers and SFBDE such that early life stage entrainment is below a level that limits juvenile recruitment.
      i. *Criteria Not Met*: Current screen criteria (developed for salmonids) may not be useful in preventing Southern DPS green sturgeon from impingement and entrainment. Currently, no screen criteria has been developed for green sturgeon. Although larger water diversions (>250 cfs) in the Sacramento River have been screened, there are still thousands of unscreened diversions (<250 cfs). Water diversions remain a threat medium threat for juvenile green sturgeon and a high priority for research and development.
   b. No threat-based criteria were developed for threats associated with competition for habitat and mortality factors associated with electromagnetic fields, anthropogenic underwater sounds, and entrainment from hydrokinetic projects.
      i. Competition for habitat and mortality factors associated with electromagnetic fields, anthropogenic underwater sounds, and entrainment from hydrokinetic projects continue to be a high or medium threat. Global climate change continues to be a very high threat.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 Background and new information on the species' biology and life history:

Research conducted and published since 2015 confirms and enhances our understanding of the biology and life history of Southern DPS green sturgeon, including reproductive characteristics. The following is a summary of this new information. Where reference is made to North American green sturgeon, the information is relevant to both DPSs or the original work did not specify the DPS under study. The DPS is specified where known. Much of the laboratory work conducted to date used Northern DPS broodstock, but the results are relevant to our understanding of green sturgeon biology and are reviewed here.

Spawning Adults: North American green sturgeon reach sexual maturity at about 15 years of age or a total length (TL) of 150-155 cm for Southern DPS individuals (Van Eenennaam et al. 2006). Southern DPS green sturgeon typically spawn every three to four years (range two to six years) and spawning occurs primarily in the Sacramento River (Brown 2007, Poytress et al. 2015, Mora et al. 2018). Since 2015, spawning has also been documented in the Feather and Yuba rivers, which are tributaries to the Sacramento River (Seesholtz et al. 2015, Beccio 2018, 2019). Adult Southern DPS green sturgeon enter San Francisco Bay in late winter through early spring, migrate upstream, and spawn from April through early July, with peaks of activity influenced by factors including water flow and temperature (Heublein et al. 2009, Poytress et al. 2015, Miller et al. 2020). Miller et al. (2020) showed that adult Southern DPS green sturgeon use the mainstem Sacramento River, Miner-Sutter Slough, and Steamboat Slough for upstream migration during spawning season.

Spawning primarily occurs in cool sections of the upper mainstem Sacramento River in deep pools (averaging 8-9 meters (m) in depth; Wyman et al. 2018) containing small to medium sized gravel, cobble or boulder substrate (Klimley et al. 2015, Poytress et al. 2015, Wyman et al. 2018). Water flow is an important cue in spawning migration for both Northern and Southern DPS green sturgeon (Benson et al. 2007, Erickson and Webb 2007, Heublein et al. 2009, Poytress et al. 2015, Steel et al. 2019). White sturgeon spawning has been documented to occur after elevated flows (Schaffter 1997, Jackson et al. 2016), suggesting a connection between flow and spawning. Brown (2007) documented Southern DPS green sturgeon spawning both above and directly below the site of the RBDD on the Sacramento River. Behavioral observations in Thomas et al. (2014) indicate that males may fertilize the eggs of multiple females. Prior to decommissioning in 2011, the gates at RBDD would be lowered for several months of the year from late spring through summer, prohibiting many Southern DPS green sturgeon from ascending upstream to spawn. Following the decommissioning of the dam, Southern DPS green sturgeon are able to access spawning habitat upstream of RBDD (Mora et al. 2018, Steel et al. 2019).

Post-spawn fish may hold for several months in the Sacramento River and out-migrate in the fall or winter or move out of the river quickly during the spring and summer months, with the holding behavior most commonly observed (Heublein et al. 2009, Mora 2016, Miller et al. 2020, Seesholtz 2020). Miller et al. (2020) documented one post-spawn adult Southern DPS green sturgeon holding for over a year in the Sacramento River and then exiting over winter. Post-spawn outmigration through the SFBDE is also variable, with some individuals migrating to the Pacific Ocean rather quickly (2-10 days) and others remaining in the estuary for a number of months after leaving upstream holding habitats

(Heublein et al. 2009, Miller et al. 2020). Post-spawn individual holding times vary and are likely influenced by delayed flow cues, which aid in outmigration (Miller et al. 2020). Miller et al. (2020) observed that although adult Southern DPS green sturgeon take several routes to reach spawning grounds, they generally migrate out of spawning grounds through the mainstem Sacramento River.

Eggs, Larvae, and Young-of-Year Juveniles: North American green sturgeon eggs primarily adhere to gravel or cobble substrates, or settle into crevices (Van Eenennaam et al. 2001, Poytress et al. 2011). See the 2015 review and 2018 Recovery Plan for the full description of egg and larvae development of green sturgeon. Temperature influences egg development and hatching rate according to laboratory studies and is likely a factor in Southern DPS recovery. In laboratory experiments, optimal temperature for egg development ranged from 14-17℃, with temperatures higher than 20℃ being detrimental for embryos (Van Eenennaam et al. 2005). Water temperature also impacts larval growth of green sturgeon. Lab experiments show optimal growth at 15℃, while temperatures less than 11℃ and temperatures greater than 19℃ decreased growth rate (Poletto et al. 2018). Juvenile Northern DPS green sturgeon can endure elevated temperatures in the laboratory (up to 28°C tested) without showing compromised swimming performance, but temperatures above 19°C were correlated with higher expression of heat shock proteins (Allen et al. 2006, Verhille et al. 2016, Poletto et al. 2018). While much of the laboratory data reviewed above have been generated using Northern DPS broodstock, it is likely applicable to the life history of the Southern DPS. Temperatures in the upper Sacramento River documented during the estimated Southern DPS spawning period had a mean temperature of 13.5°C (Poytress et al. 2015).

Green sturgeon move downstream as they transition from larvae and young-of-year into juveniles. In the laboratory, juvenile Northern DPS green sturgeon were highly tolerant to changes in salinity during the first six months (Allen et al. 2011) and the ability to transition to seawater occurred at 1.5 years of age (Allen and Cech 2007). Based on length of juvenile sturgeon captured in the SFBDE, Southern DPS green sturgeon migrate downstream toward the estuary between six months and two years of age (Radtke 1966). Sardella and Kultz (2014) found in a laboratory setting that Northern DPS green sturgeon are able to tolerate large fluctuations in salinity (from 0 g/mL to 24 g/mL over a 12-hour period); however, they will develop high levels of physiological stress from these large fluctuations (Sardella and Kultz 2014).

Juveniles, Subadults, and Adults: Since the 2015 review, more is known about Southern DPS green sturgeon rearing and foraging in the SFBDE. Several telemetry studies provide insight to juvenile, subadult, and adult habitat use in the SFBDE. As part of a three year study (2009 to 2012) with 106 acoustic receivers deployed from the Benicia Bridge to the Port of Oakland, Chapman et al. (2019) found that nine tagged adult green sturgeon were primarily detected in depths greater than five meters within the study area throughout the year. Adult green sturgeon (n = 134) were detected year-round throughout the study area, including two periods where small relative increases in overall adult green sturgeon detections were observed, February to March and June to September (Chapman et al. 2019). Chapman et al. (2019) also found that 81% of the detected green sturgeon were observed at least in one dredged area or dredged material placement site. Kelly et al. (2020) described how, during the summer and fall months of 2001 and 2002 in San Pablo Bay, two tagged green sturgeon used selective tidal stream transport to move throughout the SFBDE during daily, non-migratory movements. The tagged green sturgeon swam with the current near the surface in deeper, high-current areas of the SFBDE, and they swam along the bottom in shallow areas with little current (Kelly et al. 2020). This behavior is thought to maximize swimming efficiency and save energy for the fish. When the current was going in what was deemed to be an unfavorable direction, then the fish appeared to rest on the bottom rather than swim against the current (Kelly et al. 2020). It should be noted that this study is based on a small sample size (two green sturgeon), and that more research is needed to explore this behavior and its potential energetic benefits. A telemetry study focusing on green and white sturgeon recorded high juvenile, subadult, and adult Southern DPS green sturgeon presence year-round in the Delta, Suisun Bay, San Pablo Bay, and Central San Francisco Bay (Miller et al. 2020). Currently, a telemetry study tagging and tracking juvenile Southern DPS green and white sturgeon is being conducted in the Delta by CDFW. From 2015 to 2020, 143 juvenile Southern DPS green sturgeon have been captured and the majority of those juveniles have been tagged with acoustic telemetry tags (Beccio 2020, 2021). This study is not designed to provide abundance estimates or annual recruitment indices, but annual catch per unit effort (CPUE) indicates that successful recruitment is likely dependent on water year type. CPUE for age-0+ juveniles recruited during spawning years with high Delta outflows as determined by water year type was markedly higher than for recruitment from spawning years with lower Delta outflows (Beccio 2020).

Subadult and adult North American green sturgeon spend most of their life in the coastal marine environment. Miller et al. (2020) described subadult green sturgeon leaving the SFBDE and primarily swimming north along the Pacific Coast. As described in the 2015 review, green sturgeon typically occupy depths of 20 to 70 m while in marine habitats (Erickson and Hightower 2007, Huff et al. 2011) and make rapid vertical ascents while in marine environments, often at night (Erickson and Hightower 2007). Temperatures occupied in the marine environment ranged from 7.3 to 16°C, with a range of mean temperatures from 10.5 to 12.5°C (Erickson and Hightower 2007, Huff et al. 2011). Southern DPS green sturgeon are found in high concentrations in coastal bays and estuaries along the west coast of North America during the summer and autumn, particularly in Willapa Bay, Grays Harbor, and the Columbia River estuary (Lindley et al. 2008, Moser et al. 2016, Schreier et al. 2016). Moser et al. (2017) described feeding pits occupied by green sturgeon during summer months in Willapa Bay. Green sturgeon were documented feeding during high tide on nonvegetated littoral mud flats. Green sturgeon presence on the mud flats was negatively correlated with invasive seagrass (*Zostera japonica*) and positively correlated with the abundance of thalassinid shrimp burrows (Moser et al. 2017).

Summary: Overall, the new information on the biology of the species provides insights for protecting Southern DPS green sturgeon habitat in freshwater, estuarine, and marine environments. As noted in the 2015 review, access to spawning habitat has been improved with the decommissioning of RBDD in the Sacramento River and opening of Shanghai Bend in the Feather River Since the 2015 review, there have also been fish passage improvements at Fremont Weir. Raising the gates of RBDD eliminated a passage issue and allowed more Southern DPS green sturgeon to access spawning areas upstream of RBDD (Thomas et al. 2014, Steel et al. 2019). Recruitment data are not presently available to measure the impact of the removal of RBDD on Southern DPS reproduction. Laboratory and field studies of larval and young-of-year juvenile Northern DPS green sturgeon indicate optimal thermal regimes in freshwater environments and resilience to salinity and temperature changes. Field studies explore movement and habitat use of all life stages of green sturgeon in the freshwater, estuarine, and marine environments. Limited studies have been conducted to examine rearing and foraging of juvenile Southern DPS green sturgeon in the spawning and rearing areas of the Sacramento River Basin as well as the SFBDE. Estuaries along the west coast are important habitats for subadult and adult Southern DPS green sturgeon. Although passage improvements have occurred at Fremont Weir and spawning events have been documented in the Feather and Yuba rivers, no changes to the species status or threats are evident since the last review.

2.3.1.2 Abundance, population trends (e.g., increasing, decreasing, stable), demographic features (e.g., age structure, sex ratio, family size, birth rate, age at mortality, mortality rate, etc.), or demographic trends:

Since 2015, modeling, genetic, and field-based studies, many targeting species other than green sturgeon, have provided information on the Southern DPS green sturgeon population. However, these studies have not led to a reliable population estimate, nor do they provide information on long-term trends, and demographic features or trends needed to evaluate the recovery of Southern DPS green sturgeon because we lack data on egg-to-larva survival, juvenile recruitment, information on juveniles and subadult life stages, and mortality estimates for all life stages. We are working to gather this data for the future. For now, we will not discuss trends but will rather focus on population abundance.

A Southern DPS population estimate was developed by Mora et al. (2018) through Dual Frequency Identification Sonar (DIDSON) surveys of aggregation sites conducted from 2010-2015 in the upper Sacramento River. Mora et al. (2018) estimated the total population size to be 17,548 individuals (95% confidence interval [CI] = 12,614-22,482). The SWFSC recently updated the total population estimate to 17,723 (Dudley 2021).These surveys estimate the abundance of Southern DPS adults at 2,106 individuals (95% CI = 1,246-2,966) (Mora 2016, Mora et al. 2018). A conceptual demographic structure applied to the adult population estimate resulted in a Southern DPS subadult population estimate of 11,055 (95% CI = 6,540-15,571) and juvenile population estimate of 4,387 (95% CI = 2,595-6,179) (Mora et al. 2018). The DIDSON surveys and associated modeling will eventually provide population trend data. Demographic Criterion 4 requires that the population is characterized by a broad distribution of size classes representing multiple cohorts that are stable over at least 20 years. Continued monitoring of all life stages is needed to inform this criterion.

Spawning Adults: The 2015 review used genetic analyses from Israel and May (2010) to estimate the number of Southern DPS green sturgeon spawning individuals in the upper Sacramento River (above RBDD). The study indicated that an estimated 10-28 individual Southern DPS green sturgeon effectively reproduced upstream of RBDD in the upper Sacramento River annually (Israel and May 2010). This spawning population estimate was stable over the five year sampling period (2002-2006). It should be noted that the study was conducted prior to the decommissioning of RBDD (2011) when upriver access by Southern DPS green sturgeon to spawning habitat was limited. The Southwest Fisheries Science Center (SWFSC) continued Mora et al. (2018)'s work and conducted DIDSON surveys at aggregation sites in the upper Sacramento River from 2016-2020. Spawner abundance was estimated for the Sacramento River using the DIDSON surveys and associated modeling (Mora et al. 2018). Spawner counts (with 95% CI): 2010: 244 ± 36; 2011: 223 ± 20; 2012: 325 ± 26; 2013: 341 ± 29; 2014: 530 ± 31; 2015: 431 ± 28; 2016: 375 ± 19; 2017: 82 ± 9; 2018: 447 ± 44; and 2019: 252 ± 44 (Dudley 2020). The confidence interval is different from Mora et al. (2018) due to an error in previous reports. Actual numbers may be slightly different because of slight modification to the method of calculating the area scanned (Dudley 2020). Mora et al. (2018) also showed that spawning periodicity ranged from two to six years with the majority of repeat spawners returning every four years. Continued DIDSON monitoring of aggregation sites is needed in the upper Sacramento River to assess population abundance and establish trends. Demographic Recovery Criterion 1 requires spawning population size to be at least 500 individuals in any given year, which only occurred in 2014.

The number of holding areas (i.e., specific areas in the river where green sturgeon congregate) occupied by Southern DPS green sturgeon in the Sacramento River has not been updated since the last review. The previous review reported 22 holding areas, while there were 125 surveyed areas that were considered suitable based on depth (Mora 2016). Holding areas with sturgeon were distributed across most (i.e., 75 miles) of the study area. There was also a difference in the holding areas occupied by sturgeon during any given sampling year: some areas were occupied in all years, some in just one year, and some in two, three, or four years. Thus, there is temporal and spatial variation in the holding areas occupied by Southern DPS green sturgeon within the Sacramento River.

Juveniles: Young-of-year presence has been incidentally documented during juvenile salmonid monitoring efforts at the RBDD and near the Glenn Colusa Irrigation District (GCID) pumping facility, both located on the upper Sacramento River. Using rotary screw traps set downstream of RBDD, USFWS captured 21,057 larval Southern DPS green sturgeon from 1994 to 2020, with approximately 4,100 larvae collected in 2019. Sampling was limited in 2020 due to COVID-19 sampling restrictions; only 157 larvae were collected in 2020 (Poytress 2020). From 2015 to 2020, 224 young-of-year juvenile Southern DPS green sturgeon were captured in the Sacramento Trawl conducted by USFWS. Several juveniles were tagged with Juvenile Salmonid Acoustic Tracking (JSAT) or 303Hz tags to monitor entrance to the Delta (Poytress 2020). The 2015 review stated that over 2,000 Southern DPS green sturgeon larvae were also collected in fyke nets and rotary screw traps at GCID from 1986 to 2003. From March 2013 to December 2019, 64 Southern DPS green sturgeon juveniles were collected in the rotary screw traps at GCID (fork length [FL] 23-325 mm). Caution is needed in interpreting these data as reflective of abundance since the surveys were not designed to measure green sturgeon abundance. Annual distributions of larvae have been found to peak during June and July at RBDD (with the exception of 2012 when only a June peak was observed) and July at GCID (Adams et al. 2002, Adams et al. 2007, Poytress et al. 2015). Demographic Recovery Criterion 2 requires successful spawning of Southern DPS green sturgeon in at least two rivers within their historical range. Successful spawning has been documented for over 20 years in the Sacramento River, but successful spawning has not been consistently documented in the Feather or Yuba rivers.

Subadults and Adults: The CDFW conducts annual field sampling for sturgeon in San Pablo and Suisun Bays in the months of August through October. Reports from 2015-2019 describe encounters with relatively small numbers of subadult and, to a lesser extent, adult Southern DPS green sturgeon (2015: 18; 2016: 0; 2017: 8; 2019: 3); annual reports are available at https://wildlife.ca.gov/Conservation/Delta/Sturgeon-Study/Bibliography). Sampling did not occur in 2018 due to boat issues (Kelly 2021). Since the study is primarily designed to study white sturgeon, the results cannot be interpreted for estimates of or trends in Southern DPS abundance. Demographic Recovery Criterion 3 requires a net positive trend in juvenile and subadult abundance observed over the course of at least 20 years. There are currently no studies that address juvenile and subadult abundance of Southern DPS green sturgeon.

Since the 2015 review, ODFW and WDFW have not generated estimates of subadult and adult Northern and Southern DPS green sturgeon in Willapa Bay, Grays Harbor, and the Columbia River based on tagging and recapture studies and subsequent analysis. WDFW tagged green sturgeon in Willapa Bay and Grays Harbor in the fall of 2020 but no data have been published. During fall 2020 sampling, 123 green sturgeon were tagged with Passive Integrative Transponder (PIT) tags and 60 green sturgeon were tagged with acoustic telemetry tags. All sturgeon were sampled for blood and genetics. WDFW is monitoring sturgeon movement in the coastal estuaries with acoustic arrays (Heironimus 2021a).

Summary: In summary, recent studies provide information on the population abundance of Southern DPS green sturgeon. Future surveys and abundance estimates will provide a basis for understanding the population trajectory of the Southern DPS. Since there are no past survey data or abundance estimates that can be used as a reference point, these data do not provide a basis for changing the status of the Southern DPS. Consistent with the 2015 review, data suggest that the spawning population of the Southern DPS is smaller than the Northern DPS, which is consistent with the fact that Southern DPS is listed under the ESA, and the Northern DPS is not.

The spawning population of the Southern DPS in the Sacramento River congregates in a limited area of the river compared to potentially available habitat. The reason for this is unknown. This is concerning given that a catastrophic or targeted poaching event impacting just a few holding areas could affect a significant portion of the adult population. Removal of the RBDD barrier did allow Southern DPS green sturgeon to freely access a larger area of the river over their entire spawning period (Thomas et al. 2014), so the Southern DPS likely now holds in a larger area of the river compared to when RBDD was operating in 2011 (Mora et al. 2018, Steel et al. 2019). Continued monitoring of the adult population in the Sacramento River and its tributaries will provide valuable trend data and information to enhance spatial protection. Of note is that all of the holding areas where green sturgeon were found in the Sacramento River in the DIDSON survey area (Highway 32 overcrossing to the city of Redding) are currently included in the area where CDFW restrictions prohibit fishing for all sturgeon species (See Section 2.3.2.2). No changes to the species status or threats are evident since the last review based on the reviewed information on abundance and demographic trends.

2.3.1.3 Genetics, genetic variation, or trends in genetic variation (e.g., loss of genetic variation, genetic drift, inbreeding, etc.):

Since the 2015 review, there were no genetic studies that furthered our understanding of genetic variation or trends in genetic variation for green sturgeon. However, new genetic techniques were used to distinguish between Northern and Southern DPS in coastal estuaries and to identify green sturgeon in new locations, which provides new information on the species. In testing a new genetic technique to differentiate Northern DPS and Southern DPS, Anderson et al. (2017) observed two “extremely” different proportions of each population in two separate locations—Columbia Plume region (39 Southern DPS of 86 samples) and the Gulf of the Farallones (103 Southern DPS of 104 samples). Seesholtz et al. (2015) documented Southern DPS green sturgeon spawning in the Feather River, a tributary to the Sacramento River. Anderson et al. (2018) confirmed Southern DPS green sturgeon holding in a pool near Knights Ferry, CA in the Stanislaus River using a GoPro and eDNA techniques to confirm species.

Stillwater Sciences and Wiyot Tribe Natural Resources (2017) documented green sturgeon in the Eel River, and of the five genetic samples taken, they only found Northern DPS. Schreier et al. (2016) examined size differences between Northern DPS and Southern DPS in the Columbia River estuary, Willapa Bay, and Grays Harbor and found Northern DPS were significantly smaller than Southern DPS at 120.0 cm and 138.3 cm, respectively. They also found that the populations congregating in the Columbia River estuary and Willapa Bay were majority Southern DPS, while the populations congregating in Grays Harbor had nearly equal representation of each DPS. CDFW has also documented a single spawning event in the Yuba River in 2018 (estimated spawning date June 13) and captured a single juvenile sturgeon (from estimated spawning on July 19) during the 2019 season (Beccio 2018, 2019). During monitoring activities on April 11, 2020, a green sturgeon was captured within the boundaries of the San Joaquin River Restoration Program Area near the mouth of the Merced River in Hills Ferry, California (Root et al. 2020). The 126 cm FL green sturgeon was captured in a fyke trap that was targeting salmonids. This is the second confirmed adult green sturgeon in the San Joaquin River basin, following the adult green sturgeon in the Stanislaus River in 2017. This encounter extends the reported range of green sturgeon by ~44 river miles (RM) (Root et al. 2020). The information summarized in this section does not change the status of the species or the imminence or magnitude of any threat since the genetic data only confirm the DPS structure and add detail to the DPS composition in different estuaries during the sampling periods.

2.3.1.4 Taxonomic classification or changes in nomenclature:

There were no relevant studies examining taxonomic classification since the last status review.

2.3.1.5 Spatial distribution, trends in spatial distribution (e.g. increasingly fragmented, increased numbers of corridors, etc.), or historic range (e.g. corrections to the historical range, change in distribution of the species' within its historic range, etc.):

Work published after 2015 enhances our knowledge of North American green sturgeon spatial habitat use and distribution. As stated in the previous 5-year review, subadult (from the age of ocean entry to age of first spawning) and adult North American green sturgeon spend most of their lives in oceanic environments where they occupy nearshore coastal waters from the Bering Sea, Alaska (Colway and Stevenson 2007) to Baja California, Mexico (Rosales-Casian and Almeda-Jauregui 2009). The 2015 review indicated that North American green sturgeon are observed infrequently in Alaskan waters.

As stated in the 2015 review, telemetry data and genetic analyses suggest that Southern DPS green sturgeon generally occur from Graves Harbor, Alaska to Monterey Bay, California (Moser and Lindley 2007, Lindley et al. 2008, Lindley et al. 2011) and, within this range, most frequently occur in coastal waters of Washington, Oregon, and Vancouver Island and near San Francisco and Monterey bays (Huff et al. 2012, Moser et al. 2016). Within the nearshore marine environment, tagging and fisheries data indicate that Northern and Southern DPS green sturgeon prefer marine waters less than 110 m deep (Erickson and Hightower 2007). Further telemetry studies performed by the WDFW and NMFS-Northwest Fisheries Science Center (NWFSC) have shown a great amount of seasonal movement between the coastal bays and estuaries and the nearshore marine environment (Heironimus 2021b).

Since the 2015 review, adult and subadult Southern DPS green sturgeon have been observed in large concentrations in the summer and fall within coastal bays and estuaries along the west coast of the United States, including the Columbia River estuary, Willapa Bay, Grays Harbor, and Humboldt Bay (Moser and Lindley 2007, Lindley et al. 2008, Lindley et al. 2011, Washington Department of Fish and Wildlife (WDFW) and Oregon Department of Fish and Wildlife (ODFW) 2014, Goldsworthy et al. 2016). These areas, particularly Willapa Bay and Humboldt Bay, are likely used for foraging and possibly as thermal refugia (Moser and Lindley 2007). The Umpqua River estuary seems to be a preferred habitat for the Northern DPS (Lindley et al. 2011, Goldsworthy et al. 2016). Recent fieldwork indicates that Southern DPS green sturgeon generally inhabit specific areas of coastal estuaries near or within deep channels or holes, moving into the upper reaches of the estuary, but rarely into freshwater (Washington Department of Fish and Wildlife (WDFW) and Oregon Department of Fish and Wildlife (ODFW) 2014). Green sturgeon in these estuaries may move into tidal flats areas, particularly at night, to feed (Dumbauld et al. 2008, Moser et al. 2017). Miller et al. (2020) recorded adult and subadult Southern DPS green sturgeon presence year-round in the Sacramento-San Joaquin Delta, Suisun Bay, San Pablo Bay, and Central San Francisco Bay. Adult Southern DPS green sturgeon were tracked by ship in the SFBDE (Kelly et al. 2007, Kelly and Klimley 2012). Individual Southern DPS green sturgeon occupied the flats during low flows and moved within the channels during high flows, generally swimming near the bottom. There is some evidence that they display ‘rheotaxis,’ gaining directional information from the flow of the water (Kelly et al. 2020). Two tagged green sturgeon in San Francisco Bay displayed selective tidal stream transport to perform daily movement between tidal regions. Rather than fighting currents, the sturgeon swam into the water column when the current was favorable. The tagged green sturgeon swam along the bottom during opposing tides (Kelly et al. 2020). Southern DPS green sturgeon display within-population level diversity in their spatial and temporal use of coastal estuaries that somewhat corresponds to the individual size of the animal (Lindley et al. 2008, Lindley et al. 2011). Green sturgeon also move extensively within an individual estuary and between different estuaries (e.g., between Willapa Bay and the Columbia River) during the same season (Moser and Lindley 2007, Washington Department of Fish and Wildlife (WDFW) and Oregon Department of Fish and Wildlife (ODFW) 2014).

Lindley et al. (2008) found that most, but not all, green sturgeon annually migrate along the continental shelf, traveling from United States waters to Canadian waters in the fall and returning in the spring. They found that green sturgeon concentrate in the northwest Vancouver Island area from May through June and October through November. One tagged Southern DPS green sturgeon was detected in southeast Alaska, reinforcing the idea that green sturgeon rarely enter Alaskan waters (Lindley et al. 2008). Lindley et al. (2011) described the movements and summer occurrence of Northern and Southern DPS green sturgeon in estuarine and coastal areas such as, the Columbia River estuary, Willapa Bay, Grays Harbor, and the estuaries of smaller rivers in Oregon, particularly the Umpqua River estuary. Green sturgeon from different natal rivers exhibited different patterns of habitat use, with the SFBDE used only by the Southern DPS and the Umpqua River estuary used mostly by the Northern DPS. The Columbia River was visited by both Southern and Northern DPS green sturgeon. Although adults have been detected throughout the SFBDE year-round, spawning Southern DPS adults often use the SFBDE as a migration corridor, passing through within a few days of entering the SFBDE (Heublein et al. 2009, Miller et al. 2020). Subadults and non-spawning adults utilize the SFBDE in the summer for other reasons, possibly to feed, as residency periods are longer (Lindley et al. 2011, Miller et al. 2020). Recent data from telemetry studies from the NWFSC show large concentrations of tagged green sturgeon entering the coastal bays and estuaries of Oregon and Washington during the fall months with migrations into the nearshore marine environment along the Canadian coast in the winter (Smith and Huff 2020).

Section 2.3.1.1 describes current knowledge regarding spawning behavior and timing of Southern DPS green sturgeon in the Sacramento River below Keswick and Shasta dams. Whether Southern DPS green sturgeon historically spawned above Keswick and Shasta dams has been debated (Beamesderfer et al. 2005), with the original status review indicating spawning in the tributaries upstream of those dams (Adams et al. 2007). An analysis based on the habitat occupied at present versus the habitat available above the dams indicates that Southern DPS green sturgeon likely occupied areas above the dams before their construction (Mora et al. 2009, Mora et al. 2018). Adult green sturgeon have been observed in other rivers such as the lower Yuba River downstream of Daguerre Point Dam (Mora et al. 2018), and spawning was documented in the lower Yuba River by CDFW in 2018 and 2019 (Beccio 2018, 2019). Although sturgeon have been observed in the Russian River, the only known photo is of a white sturgeon. Data from angler self-reporting through the Sturgeon Report Cards distributed by CDFW indicate reports of two green sturgeon in the San Joaquin River upstream of designated critical habitat between 2016 and 2020 (See Table 1). Modeling indicates that spawning could have been supported in the San Joaquin River based on the habitat that existed in this system historically (Mora et al. 2009, Mora et al. 2018). Additionally, two confirmed green sturgeon were documented in the San Joaquin River Basin since the 2015 review (Anderson et al. 2018, Root et al. 2020).

As stated in Section 2.2.3, Demographic Recovery Criterion 2 requires the annual presence of larvae for at least 20 years in at least two rivers within Southern DPS historical range to show that green sturgeon are successfully spawning. The 2015 review noted that Southern DPS green sturgeon spawning was documented the Feather River (Seesholtz et al. 2015). Since 2015, a total of 19 green sturgeon eggs were collected in the lower Feather River using egg mats. Egg mats were placed near the Fish Barrier Dam pool (RM 67, n = 2) in 2017 and in the Thermalito Afterbay Outlet pool (RM 59, n = 17) in 2019. The eggs were found in temperatures that ranged from 13.3-19.5℃. Genetic analysis was not completed for these eggs; however, it is likely that they are genetically Southern DPS (Seesholtz 2020). In 2018, a larval sturgeon was sampled in the Feather River below the confluence of the Yuba River, which suggests that a spawning event occurred in either the Feather or Yuba River. DIDSON studies indicate that Southern DPS green sturgeon adults are present in the Feather River every year. Studies also indicate that spawning habitat in the Feather River extends from the Thermalito Afterbay Outlet pool upstream to the Fish Barrier Dam, which can only be accessed by green sturgeon in years with high basin discharge (Seesholtz 2020). In years of low basin discharge, green sturgeon are unable to access habitat upstream of Sunset Pumps rock weir (RM 38.5). A total of 14 larval green sturgeon were sampled using benthic d-nets in the lower Feather River, with 11 larvae sampled in the Fish Barrier Dam pool in 2017 and three larvae sampled near Boyd’s Pump in 2018. Larvae were collected in water temperatures that ranged from 13-18℃. This evidence suggests that the Feather River is able to support periodic reproduction of green sturgeon, primarily in years with high water discharge. Continuous spawning needs to occur for at least 20 years to meet Demographic Recovery Criterion 2.

Since 2015, 402 ARIS/DIDSON sonar surveys have been performed in the lower Feather River from the Fish Barrier Dam downstream to Beer Can Beach (RM 7). The majority of the surveys occurred in four areas: Fish Barrier Dam, Thermalito Afterbay Outlet, Sunset Pumps rock weir, and Oswald (RM 23). A total of 747 images of sturgeon were recorded during these surveys. No detections above the Sunset Pumps rock weir occurred in the drier years of 2015 and 2016. In the wetter years of 2017, 2018, and 2019, green sturgeon were detected upstream of Sunset Pumps rock weir when mainstem discharge was higher, which provided sufficient flows for migration above the weir into spawning grounds. A total of 16 Southern DPS adult green sturgeon have been tagged in the lower Feather River basin since 2015. The majority of these fish were tagged in 2018 following spawning season. Since 2015, 22 previously tagged Southern DPS green sturgeon adults were detected in the lower Feather River; however, only three of the 22 were detected above Sunset Pumps rock weir. No telemetry detections occurred at Sunset Pumps rock weir in years of average or below average basin discharge. Green sturgeon detections in the lower Feather River align with the spawning season, with the average first detection occurring March 30. Following the spawning season, the majority of acoustically-detected green sturgeon leave the lower Feather River; however, a small amount of green sturgeon remain for several months in holding areas of the river such as Oswald (Seesholtz 2020). The DIDSON and acoustic telemetry data suggest that adult green sturgeon use the Feather River for both spawning and holding areas. In years of low water, green sturgeon are restricted to habitat downstream of the Sunset Pumps rock weir, which acts as a barrier to upstream migration. Providing upstream passage at Sunset Pumps rock weir (Priority 2 Recovery Action 1a) increases access to spawning habitat for Southern DPS green sturgeon.

The 2015 review indicated that green sturgeon were observed in the lower Yuba River below the Daguerre Point Dam (11.5 RM). In order to document green sturgeon spawning in the Yuba River, egg mats were deployed in the pool downstream of Daguerre Point Dam in 2018 and 2019. Approximately 270 green sturgeon eggs were collected on a single egg mat on June 15, 2018; the eggs were vouchered for species verification and developmental staging to determine spawning date, which was June 13, 2018 (Beccio 2018). No green sturgeon eggs were collected in 2019, but an early-stage juvenile green sturgeon (40 mm FL) was observed and captured by hand in edgewater habitat 200 m downstream of Daguerre Point Dam on August 19, 2019. The spawning event likely occurred on July 19, 2019 (Beccio 2019). These spawning events suggest that the Yuba River has the potential to support periodic reproduction of Southern DPS green sturgeon. Continuous spawning needs to occur for at least 20 years to meet Demographic Recovery Criterion 2. Green sturgeon are frequently observed holding below Daguerre Point Dam, which is the current extent of anadromy for green sturgeon in the Yuba River. Greater access to spawning habitat is needed to meet Demographic Recovery Criterion 2. Providing upstream passage at Daguerre Point Dam (Priority 2 Recovery Action 1c) will increase access to spawning habitat. Assessing the water temperature and flow in the Yuba River to provide suitable conditions for spawning and rearing green sturgeon (Priority 2 Recovery Action 2c) will aid juvenile recruitment.

Schreier et al. (2016) describes preliminary evidence of green sturgeon spawning in the Columbia River based on the collection of an age-0 individual near Rooster Rock (RM 130). However, genetic analyses assigned this individual to the non-ESA listed Northern DPS rather than the listed Southern DPS. Schreier and Stevens (2020) captured four young-of-year green sturgeon downstream of Bonneville Dam on the Columbia River in 2017. Genetic analysis revealed that the fish are Northern DPS, confirming that the Northern DPS spawns in at least three rivers. Young-of-year green sturgeon were only detected in the Columbia River in times of high spring flow (e.g., 2011 and 2017)(Schreier and Stevens 2020)

Data generated since 2015 regarding the spatial occupancy of Southern DPS green sturgeon reinforces the DPS structure and the importance of coastal and estuarine habitats along the west coast of the United States. New research documents spawning by the Southern DPS in the Feather and Yuba rivers multiple years (Seesholtz et al. 2015, Beccio 2018, 2019, Seesholtz 2020), but does not meet Demographic Recovery Criterion 2, continuous spawning for 20 years. Several Recovery Actions from the 2018 Recovery Plan directly call for barrier removal or modification in the Sacramento, Feather, and Yuba rivers so that successful spawning occurs annually in at least two rivers. Water temperature and flows in spawning and rearing areas should also allow for juvenile recruitment. While this research gives greater insight into the geographic areas occupied by the Southern DPS, the research shows that spawning in the Feather and Yuba rivers is periodic, not continuous. Given the limited number of occurrences and lack of consistent successful spawning events in additional spawning locations, this threat remains. Based on this, the new information does not support any change in species status.

2.3.1.6 Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):

Altered Water Flow and Temperature in Spawning Habitat: A primary concern for Southern DPS green sturgeon identified in the 2018 Recovery Plan is spawning habitat suitability in terms of water flow and temperature in the Sacramento, Yuba, and Feather rivers. Comparative analyses of historic and contemporary hydrologic and thermal regimes indicate that habitats in all of these rivers are different than they were before dam construction (see Section 2.3.2.1). What is less clear is the impact that this has had on green sturgeon spawning and recruitment. Mora et al. (2009) suggest that flow regulation has had mixed effects on habitat suitability.

Wyman et al. (2018) modeled habitat suitability for known spawning areas within the Sacramento River. Models indicated that adult Southern DPS green sturgeon are found in spawning locations that had velocities between 1.0 and 1.1 m/s, depths of 8-9 m, and gravel and sand substrate (Wyman et al. 2018). Following Wyman et al. (2018)'s model, Klimley et al. (2020) used habitat suitability modeling to better understand the relationship between population decline, habitat suitability, and the remaining available spawning habitat for Southern DPS green sturgeon. Klimley et al. (2020) used the habitat suitability of three known spawning pools in the Sacramento River and compared the amount of spawning habitat by water year. Available spawning habitat was reduced in one of the three pools during the four year drought period, from 2012 to 2015 (Klimley et al. 2020). Modeling habitat suitability of spawning habitat for Southern DPS green sturgeon should continue to be studied. It is likely that climate change and other factors will impact the habitat suitability of spawning areas for Southern DPS green sturgeon.

Barriers to Migration: The 2018 Recovery Plan listed barriers to migration as a threat to Southern DPS green sturgeon. Flood bypass systems along the Sacramento River pose a potential entrainment threat to Southern DPS green sturgeon during spawning migrations. Green sturgeon are particularly affected by Tisdale (Sutter Bypass) and Fremont (Yolo Bypass) weirs (Thomas et al. 2013, Beccio 2020, DWR 2020). Fish rescues were conducted by CDFW after overtopping events at Fremont and Tisdale weirs during water years 2016, 2017, and 2019. Overtopping events occurred during the Southern DPS spawning migrations. CDFW rescued one adult Southern DPS green sturgeon in 2016 from the Fremont Weir stilling basin. Three adult Southern DPS green sturgeon were rescued from the Tisdale Weir stilling basin and two adult Southern DPS green sturgeon were rescued from the Fremont Weir stilling basin during water year 2017 (Beccio 2020). In water year 2019, 25 adult Southern DPS green sturgeon were rescued at Tisdale and Fremont weirs, which represents about 7.2% of the average annual spawning population, given the current average estimate of 348 individuals (Mora et al. 2018, Beccio 2020).

Although rescuing entrained sturgeon from flooded bypasses is important for population viability, fish passage improvement, rather than continued fish rescue, is a more appropriate long-term goal for mitigating this threat. Improvements to Yolo Bypass were part of required actions in the Reasonable and Prudent Alternative (RPA) within the biological and conference opinion on the long-term operations of the Central Valley Project and State Water Project (NMFS 2009a, 2011). Since the 2015 review, passage has been improved, but not completely remediated, at Fremont Weir for sturgeon and salmonids. The Fremont Weir Adult Fish Passage Project was completed in late 2018. The weir overtopped 4 times during water year 2019. This fish passage facility documented at least 76 sturgeon (80 to 200 cm TL) via Adaptive Resolution Imaging Sonar (ARIS) footage using the passage structure to access the Yolo Bypass (DWR 2020). Stranding of adult Southern DPS green sturgeon still occurred in a section of the Fremont Weir stilling basin and a deep scour pond approximately 140 m downstream of the weir (Beccio 2020). Continued improvements to Fremont Weir will occur with the Yolo Bypass Salmonid Habitat Restoration and Fish Passage Project (Big Notch Project), which is scheduled for completion in fall 2023 (DWR 2020). The Tisdale Weir Rehabilitation and Fish Passage Project (located at the Sutter Bypass) is scheduled for completion in 2023/2024 (DWR 2020). CDFW will continue to perform stranding surveys and rescue operations for adult sturgeon at Tisdale and Fremont weirs (Beccio 2020).

The decommissioning of RBDD, a barrier to migration in the Sacramento River, has increased the availability and use of upstream spawning habitat of Southern DPS green sturgeon (Thomas et al. 2014, Steel et al. 2019). Habitat modeling studies display that in the absence of impassable dams, Southern DPS green sturgeon would likely spawn in additional areas within the Sacramento River (Mora et al. 2009). This modeling work also found that suitable spawning habitat historically existed in portions of the San Joaquin, lower Feather, American, and Yuba rivers, much of which is currently inaccessible to green sturgeon due to the presence of barriers.

San Joaquin River Basin Habitat Suitability: Historic spawning habitat likely existed for Southern DPS green sturgeon within the San Joaquin River basin (Mora et al. 2009). Designated critical habitat for Southern DPS green sturgeon does not extend past the Delta in the San Joaquin River basin (74 FR 52300). However, since the last review, green sturgeon were documented in the Stanislaus River (Anderson et al. 2018) and San Joaquin River (Root et al. 2020). In late September and early October 2017, a genetically confirmed green sturgeon was documented in the Stanislaus River holding in a pool near Knights Ferry, California, which is approximately 53 RM upstream of designated critical habitat (Anderson et al. 2018). Self-reporting angler Sturgeon Report cards from CDFW also indicate that green sturgeon have been observed within the San Joaquin River basin (DuBois and Danos 2017). In April 2020, a green sturgeon was observed within the bounds of the San Joaquin River Restoration Program area of the San Joaquin River, which is approximately 44 RM upstream of designated critical habitat (Root et al. 2020). The fish was captured in a fyke trap 300 m upstream of the confluence of the Merced and San Joaquin rivers near Hills Ferry, California (Root et al. 2020). The green sturgeon was confirmed by trained fish biologists who evaluated external meristic characteristics. It should be noted that the 141.8 cm TL fish was documented in the San Joaquin River basin during the spawning period for Southern DPS green sturgeon (Root et al. 2020). Monitoring efforts for green sturgeon within the San Joaquin River basin should be increased to further understand their habitat extent.

Altered Prey Base: The 2018 Recovery Plan listed altered prey base as threat to Southern DPS green sturgeon throughout its critical habitat. The 2015 review stated that two issues may affect prey resources for Southern DPS green sturgeon in coastal bays and estuaries (WDFW and ODFW 2014). The first issue was the increasing presence of Japanese eelgrass (*Zostera japonica*) in tidal areas including sturgeon feeding pits, which would negatively impact the habitat of burrowing shrimp, a common prey item of green sturgeon in estuaries. Moser et al. (2017) found a negative correlation between green sturgeon presence in feeding pits and the presence of Japanese eelgrass, indicating that sturgeon may have difficulty feeding in substrate that has been invaded by Japanese eelgrass. Since 2015, the presence of Japanese eelgrass has been decreasing in the upper intertidal mudflats in coastal estuaries of Northern California, Oregon, and Washington (Goldsworthy 2020). Information is not yet available regarding the impacts of these changes on green sturgeon. An invasive, parasitic isopod that castrates the native blue mud shrimp (*Upogebia pugettensis*) (Dumbauld et al. 2008, Dumbauld et al. 2011, Chapman et al. 2012) has affected the availability of this green sturgeon prey resource in west coast estuaries.

Summary: New information on Southern DPS habitat indicates that the Southern DPS still face threats posed by impassable barriers and flood bypass systems. The decommissioning of RBDD has, however, resulted in additional spawning habitat availability and utilization. Fish passage improvement at Fremont Weir has reduced entrainment into the Yolo Bypass but fish rescues still need to occur. Continued fish passage improvement at flood bypasses will help reduce entrainment of Southern DPS green sturgeon. Hydrological and thermal regimes in spawning habitats are altered as compared to historic profiles, which could impact recruitment and recovery (see Section 2.3.2.1). New documentation of green sturgeon in the San Joaquin River basin has increased the need for monitoring green sturgeon outside of its designated critical habitat. Invasive species may impact Southern DPS prey resources in coastal estuaries. Overall, the new information does not provide conclusive data indicating that habitat conditions and factors have changed in severity or degree of threat since 2006, since additional research is needed.

2.3.1.7 Other:

None.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

Barriers to Migration and Spawning Habitat: The final rule listing Southern DPS green sturgeon indicates that the principle factor for the decline in the DPS is the reduction of spawning to a limited area in the Sacramento River (71 FR 17757; April 7, 2006). Keswick Dam on the Sacramento River and Oroville Dam on the Feather River were noted as impassable barriers (71 FR 17757). No change in the status of these dams has occurred since 2006. Potential barriers to adult migration also included RBDD, Sacramento Deep Water Ship Channel locks, Fremont Weir (Yolo Bypass), Tisdale Weir (Sutter Bypass), the Anderson Cottonwood Irrigation District (ACID) dam and the Delta Cross Channel Gates on the Sacramento River, and Shanghai Bend and Sunset Pumps rock weir on the Feather River (BRT 2005, 71 FR 17757). The Fish Barrier Dam on the Feather River and the Daguerre Point Dam on the lower Yuba River are also recognized as limiting the distribution of the Southern DPS (74 FR 52300; October 9, 2009).

Since the listing decision, some improvements to impassable barriers have occurred. Two barriers originally cited in the listing decision as posing a limit to distribution have improved since the listing: RBDD (RM 243) on the Sacramento River and Shanghai Bend on the Feather River. The decommissioning of RBDD in 2011 now permits passage of the Southern DPS during all months that they are present in the river. The breach of Shanghai Bend on the Feather River in early 2012 likely eliminated this naturally-formed passage barrier (flow-dependent) in the lower Feather River (NMFS 2015). Structural modifications at Fremont Weir (Yolo Bypass) improved passage for salmonids and sturgeon to move from the Yolo Bypass back into the Sacramento River with the first facility opening in 2019. The project permitted the passage of over 70 sturgeon during overtopping events (DWR 2020). However, three more fish passage facilities are planned at the Fremont Weir to prevent the need for fish rescue at the site. There are also plans to improve fish passage at Sutter Bypass (Tisdale Weir) and Sacramento Bypass (Sacramento Weir). On the Feather River, Sunset Pumps rock weir removal was funded by the Central Valley Project Improvement Act in 2018; however, as of this review, the project has not been initiated. Although some barriers to migration have been improved or removed, there are still many migration barriers within the Sacramento River basin. Through the development of fish passage criteria for sturgeon, many more of these barriers can be improved or removed from Southern DPS green sturgeon critical habitat.

Altered Water Flow and Temperature in Spawning Habitat: Temperature and flow have been shown to be relevant parameters with respect to spawning, survival, and growth of North American green sturgeon (see Section 2.3.1). In the Sacramento River, the Proposed Action for the long-term operations of the Central Valley Project and State Water Project (USBR 2019) includes maintenance of 11.9°C (53.5°F) water temperature from May 15 to October 31 at a compliance point above the confluence of the Sacramento River and Clear Creek in years when the U.S. Bureau of Reclamation determines that the Shasta Reservoir cold water pool is sufficient. In years when the cold water is insufficient, a tiered system attempt to optimize the use of cold water for Sacramento River winter-run Chinook salmon will be used. However, during 2014 and 2015, the lack of cold water stored behind Shasta Dam, in combination with water release decisions, led to a high water temperatures below Shasta Dam. Additional temperature requirements are mandated by the California State Water Resource Control Board Water Rights Orders 90-05 and 91-01. The CALFED Science Review Panel determined that temperatures associated with the Clear Creek compliance point may reduce the growth rate of larvae and post-larvae sturgeon relative to warmer temperatures (CALFED 2009). Balanced water temperature management may still be possible in all but the most severe drought years since the water warms as it flows downstream from the release point to the Southern DPS green sturgeon spawning sites, and given the presence of the larval green sturgeon primarily in May, before the peak agricultural water demand in June and July (Zarri et al. 2019).

As stated in the 2015 review, Mayfield and Cech (2004) reported optimal bio-energetic performance of age 0 and age 1 Northern DPS green sturgeon from 15 to 19°C in laboratory conditions. Summer water temperatures in the upper Sacramento River have typically been below this range, generally below 16℃ (Goto et al. 2015). The2015 review noted that the water temperature target of 13.3℃ was not maintained in the Sacramento River during periods of 2014 and 2015 due to the historic drought. Water temperatures increased throughout the Southern DPS green sturgeon spawning range in the Sacramento River. Summer flows also decreased as a result of the drought conditions. The effects of these water temperature and summer flow changes in the Sacramento River on survival and recruitment of green sturgeon remains unclear.

Goto et al. (2015) suggested that the managed temperature may inhibit growth rates of green sturgeon making juvenile green sturgeon more susceptible to size-dependent predation. Larval green sturgeon reared in the laboratory exhibited reduced growth at lower temperatures (i.e., 11℃ vs. 19℃) even with optimal feeding (Poletto et al. 2018). A diet study of wild larval Southern DPS green sturgeon observed that there were more empty stomachs at colder temperatures, which may indicate that foraging activities or greater food availability occur during warmer temperatures (Zarri and Palkovacs 2019). Hamda et al. (2019) developed a model to analyze the impact of different conditions in the Sacramento River (i.e., water temperature, flow, food availability) on the growth of juvenile green sturgeon. Since water temperature and flow are managed in the Sacramento River to allow for egg-to-fry survival for winter-run Chinook salmon during the same time of Southern DPS green sturgeon spawning, egg incubation, and juvenile rearing, the impact of cooler temperatures on juvenile green sturgeon growth rate was analyzed (Hamda et al. 2019). The model showed that although there is a trend for cooler temperatures to negatively impact growth rates of juvenile green sturgeon, the impact is relatively small. However, in years of warmer water temperatures, the trade-off is much greater for winter-run Chinook salmon with a large reduction in egg-to-fry survival (Hamda et al. 2019). The impact of climate change will be discussed more in Section 2.3.2.5. Further green sturgeon monitoring may produce juvenile year class indices to compare effects of water temperature and flow on recruitment in the future.

Summary: In summary, the available information generated since the 2015 review indicates that impassable barriers still pose high threat to Southern DPS green sturgeon, although the threat is reduced with the decommissioning of RBDD and passage improvement at Fremont Weir. With the decommissioning of RBDD, Southern DPS green sturgeon are spawning in greater numbers in higher reaches and larvae are now rearing in the area influenced by the cooler water temperatures closer to the temperature compliance point. That said, the compliance point has not been consistently maintained and summer flows were reduced during the 2014 and 2015 drought. The effect of the temperature on Southern DPS production during the drought remains unclear. Although the first successful season of direct juvenile green sturgeon sampling by trawling near RBDD occurred during elevated temperatures in 2015, juveniles were subsequently collected from sampling efforts from 2016 to 2020 (NMFS 2018, Poytress 2020). Furthermore, high larval Southern DPS green sturgeon catch at RBDD has occurred in years with relatively low water temperatures (1995, 2011, 2016, 2017, and 2019; NMFS 2018, Poytress 2020). The effect of cold water releases from Keswick Dam may have a greater impact on Southern DPS green sturgeon spawning and incubation in the uppermost accessible reach of the Sacramento River below the ACID. If spawning occurs immediately downstream of the ACID, then the water will not warm to more suitable temperatures for eggs and larvae as it will at spawning locations further downstream near RBDD. The ACID is a migration barrier for Southern DPS green sturgeon, but low water temperature could deter Southern DPS spawning even if passage was restored to this reach (NMFS 2019). Klimley et al. (2020) noted that over the drought (2012 to 2015), spawning habitat was reduced in one of three sites in the Sacramento River. The reduction in available spawning habitat may impact Southern DPS green sturgeon occupation in these areas (Klimley et al. 2020). Laboratory, modeling, and field studies continue to look at the impact of flow and temperature regimes on spawning and recruitment of the Southern DPS. Given the present data, there is no evidence that the threat posed by modification of habitat has increased in severity since 2015.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

In the final rule, past and present commercial and recreational fishing as well as poaching, were recognized as factors that pose a threat to the Southern DPS (71 FR 17757; April 7, 2006). No estimate of an annual rate of mortality due to poaching has become available since the last review. As stated in the previous review, the threat posed by commercial and recreational fishing has decreased since 2006 given that intentional lethal take of green sturgeon has been prohibited through fishing regulations. Regulations prohibit retention of green sturgeon in California, Oregon, and Washington state fisheries and in federal fisheries in the United States and Canada. These regulations pertain to the range of both Southern and Northern DPS green sturgeon to address the possibility of capture of the threatened Southern DPS throughout the coast.

Retention of North American green sturgeon is not currently permitted in any state fishery. The CDFW, WDFW, and ODFW all prohibit the commercial retention and sale of green sturgeon. The CDFW further prohibits take of any sturgeon (white or green) in the Sacramento River between Keswick Dam to the Highway 162 Bridge in order to protect spawning green sturgeon (CCR, Title 14, Sec. 5.80, 5.81).

State officials performed observations of commercial fisheries in the lower Columbia River and Grays Harbor and Willapa Bay estuaries to detect rates of encounters with green sturgeon. Encounters occurred mostly in the summer/fall period. From 2014 to 2019, observers encountered 5 to 24 green sturgeon per year in the Willapa Bay commercial salmon fishery (Observer coverage ranged from 15-29% per year; (Heironimus 2020b)). In Grays Harbor, observers have not recorded any catch of green sturgeon in commercial fisheries since 2014(Heironimus 2020a). For the lower Columbia River, commercial fisheries encounter up to an estimated 252 Southern DPS green sturgeon per year (NMFS 2018). No error range was provided with this point estimate. These estimates are likely to be overestimates because they are based on historical catch numbers; additional catch data are needed to refine these estimates.

Agency statistics from self-reporting and observation provide additional information about North American green sturgeon encounters in recreational fisheries in Washington and Oregon. Based on ODFW creel surveys from 2007 to 2019, the number of green sturgeon caught and released in the lower Columbia River ranged from 13 to 255 per year; no green sturgeon were reported as caught and released in 2014 (Stevens 2020). A small number of green sturgeon (≤10) are still annually retained in this fishery due to misidentification (WDFW and ODFW 2014).This number is far fewer than the number of animals that were retained before retention was prohibited in 2007 (up to 533 individuals in 1985). Of the green sturgeon encountered, the majority would be expected to be Southern DPS green sturgeon based on Israel et al. (2009).

Outside of the Columbia River, anglers in Oregon reported catch and release of 6 to 120 green sturgeon per year in 2007 through 2018 (ODFW Sport Catch Statistics 2007-2018 accessed at www.dfw.state.or.us/resources/fishing/sportcatch.asp). No green sturgeon catch was reported in years 2011, 2012, 2013, and 2017 in areas outside of the lower Columbia River. The previous review stated that recreational fisheries outside of the Columbia River in Washington may encounter up to 64 Southern DPS green sturgeon annually (NMFS 2015). No green sturgeon have been reported in Washington coastal and Puget Sound recreational fisheries (outside of Willapa Bay and Grays Harbor) since the 2007 closure to retention, although anglers are only required to report fish kept, not those released.

Southern DPS green sturgeon are encountered annually by California recreational fishers based on self-reporting and creel data. Table 1 summarizes data from sturgeon report cards submitted annually by anglers. From 2007 to 2017, the number of green sturgeon caught and released ranged from 89 to 311 per year, the average fork length ranged from 29 to 40 inches, and the main areas where green sturgeon were encountered were the Sacramento River from Rio Vista to Chipps Island, as well as Suisun Bay (Table 1). Creel surveys conducted in recreational fisheries also report green sturgeon encounters. California commercial passenger fishing vessels (CPFV) report encounters with sturgeons, but have not recorded sturgeon to the species level in the past. CPFV operators were instructed to record sturgeon to the species level in 2012. As of this review, no data was available from CPFV reports.

Table 1. Information collected through CDFW sturgeon report cards. ND = no data available. Data sources: Gleason *et al.* 2008; Dubois *et al.* 2009-2012, 2014; Dubois 2013; DuBois and Harris 2015 and 2016; DuBois and Danos 2017, 2018.

Year	# Cards Issued[1]	# Cards Returned[1]	# Cards with Sturgeon Recorded[1]	# Green Sturgeon Released	Average Fork Length of Green Sturgeon Measured at Release	Main Areas Encountered
2007[2]	37,680	6,919	1,855	311	37 inches	Sac. River Red Bluff to Colusa, Rio Vista to Chipps Island
2008	53,777	7,329	2,048	240	31.6 inches	Sac. River Red Bluff to Colusa, Rio Vista to Chipps Island

2009	72,499	8,558	2,208	215	29 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2010	66,357	7,515	1,758	151	40 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2011	112,000	12,413	2,274	89	31.3 inches	San Pablo Bay, Suisun Bay
2012	112,800	12,637	2,052	175	36 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2013	50,915	10,642	2,290	168	32 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2014	49,260	12,076	2,645	154	32 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2015	48,337	14,382	2,870	192	30 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2016	47,617	15,674	2,997	220	33 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2017	44,374	14,872	2,814	230	33 inches	Sac. River Rio Vista to Chipps Island, Suisun Bay
2018[3]	44,146	14,368	2,398	ND	ND	ND
2019[3]	40,844	12,596	1,742	ND	ND	ND

[1] Updated data obtained from DuBois et al. 2020 for the number of cards issued, returned, and with sturgeon recorded.
[2] Note that 2007 data are not from the entire year since the report card program started that year and cards were first issued in February 2007.
[3] For 2018 and 2019, data are not available on the number of green sturgeon released and the average fork length of measured green sturgeon. Data on the number of sturgeon report cards issued, released, and with sturgeon recorded were obtained from DuBois et al. 2020.

Both Southern and Northern DPS green sturgeon are encountered in the state-regulated California halibut bottom trawl fishery in coastal marine waters. From 2002 through 2017, a range of 29 to 786 green sturgeon encounters occurred per year in the fishery (Richerson et al. 2019). The majority of the green sturgeon encountered likely belonged to the Southern DPS, based on the location of the encounters (primarily in coastal marine waters adjacent to San Francisco Bay) (Richerson et al. 2019) and genetic data (Anderson et al. 2017). In 2017, one green sturgeon was caught in the California nearshore fixed-gear fishery near the mouth of San Francisco Bay, using hook and line gear (Richerson et al. 2019). The fish dropped off the line before it could be brought on board, so no data were collected on the fish size, weight, and condition, but the fish was at the surface long enough for visual identification. This was the first time green sturgeon bycatch has been observed in the California nearshore fixed-gear fishery since observer coverage began in 2002.

The 2015 review stated that in Alaska, North American green sturgeon is listed as a "nominee" species in the State of Alaska Wildlife Action Plan and designated as a "Species of Greatest Conservation Need" under the Aquatic Habitat Implementation Plan, which is part of the Comprehensive Wildlife Conservation Strategy. The Alaska Department of Fish and Game (ADFG) indicates that information about green sturgeon is limited to a few anecdotal reports of sightings and captures in Alaska waters, mostly in Alaska District 8 and District 11 (encompassing the mouths of the Stikine and Taku, respectively) driftnet fisheries. ADFG has received no reports of regular sightings of sturgeon. The North Pacific Groundfish Observer Program, which observes Federal groundfish fisheries off Alaska, has recorded rare encounters with green sturgeon in trawl fisheries in the Bering Sea (1982:1; 1984:2; 2005:1; 2006:3; 2009:1; 2012:1; 2013:1; 2015:1; NPGOP data received April 2015). It is unknown whether the green sturgeon encountered belonged to the Northern DPS or the Southern DPS.

In Canada, North American green sturgeon are occasionally encountered by commercial bottom trawlers, with most catches off the north or southwest ends of Vancouver Island. The species is also encountered at low rates in commercial hook-and-line fisheries, in the recreational white sturgeon fishery in the lower Fraser River, and in commercial salmon gillnet and seine fisheries in the Fraser River as well as at the mouths of other rivers (Fisheries and Oceans Canada 2017). Green sturgeon is listed as a species of Special Concern under Canada's Species at Risk Act (SARA) and is protected by the federal Fisheries Act, which prohibits destruction of fish habitat. A Management Plan for the species is required under the SARA and was finalized in 2017 (Fisheries and Oceans Canada 2017).

As summarized in the 2015 review, Canada prohibits retention of North American green sturgeon in recreational and commercial fisheries, and all commercial fisheries are required to release bycatch at sea with the least possible harm. The commercial groundfish bottom trawl fishery has 100% at-sea observer coverage, while the commercial hook and line/trap groundfish fisheries have 100% at-sea monitoring as either observers or electronic monitoring. Dockside monitoring is also in place for groundfish (i.e., groundfish trawl, rockfish hook and line, sablefish, halibut, lingcod and dogfish). This monitoring, in addition to logbooks, enables more accurate accounting of green sturgeon bycatch in these fisheries. Food, social and ceremonial First Nations fisheries may retain green sturgeon if they are encountered. No capture statistics are available for these fisheries.

Canadian fisheries closures established to protect large areas of significant bottom habitat (e.g., rockfish conservation areas and groundfish bottom trawl closures) also serve to protect some North American green sturgeon habitat. Additionally, standard operating practices for industries and regulatory agencies with authority in the Fraser River have been developed to mitigate impacts to freshwater habitat for green sturgeon.

Take of Southern DPS green sturgeon in Federal fisheries was prohibited as a result of the ESA 4(d) protective regulations (ESA 4(d) Rule) issued in 2010 (75 FR 30714; June 2, 2010). Northern and Southern DPS green sturgeon are, however, incidentally encountered in the west coast Pacific Groundfish fisheries, including the Limited Entry (LE) groundfish bottom trawl sector and the at-sea Pacific hake/whiting sector (at-sea hake sector) (Richerson et al. 2019). Incidental catch of green sturgeon in these fisheries has varied over the years. The LE groundfish bottom trawl sector encountered an estimated 0 to 43 green sturgeon per year from 2002 through 2017 (Richerson et al. 2019). Based on the location of the encounters and data on green sturgeon stock composition in marine and coastal estuarine waters, the majority of the green sturgeon encountered likely belonged to the Southern DPS (Anderson et al. 2017). Most of the fish were released alive. In the at-sea hake sector, three green sturgeon were encountered from 1991 through 2017 and all had died (Richerson et al. 2019). Data are not available on whether the fish belonged to the Southern DPS or Northern DPS.

Assessing the potential effects of fisheries bycatch on Southern DPS green sturgeon in commercial and recreational fisheries requires an understanding of bycatch mortality using different gear types. While immediate mortality can be more directly measured and detected and is expected to be low, some delayed mortality may occur. The issue of delayed, post-release mortality requires further study. Robichaud et al. (2006) estimates post-release mortality at 5.2% in commercial gillnet fisheries and 2.6% in recreational hook-and-line fisheries. A satellite tagging study in collaboration with the California halibut fishery estimated post-release mortality for green sturgeon to be 18% (95% CI: 6-28% mortality) (Doukakis et al. 2020). Green sturgeon are also episodically encountered and potentially injured in traps used for the Dungeness Crab fishery along the California Coast (Goldsworthy 2017). Efforts made by state and federal agencies to monitor, minimize, and evaluate the effects of fisheries capture of green sturgeon are ongoing. Studies to better understand the circumstances under which bycatch mortality increases are needed to guide fishery management efforts.

Outreach by CDFW, ODFW, and WDFW has been undertaken regarding North American green sturgeon catch and handling regulations. State commercial and sport fishing rules pamphlets indicate prohibitions on green sturgeon retention. These regulations, as well as posters at boat launch and bank fishing sites also offer information on distinguishing between green and white sturgeon. WDFW requires commercial gillnet fishers in Willapa Bay and Grays Harbor to report all green sturgeon encounters. In 2012, WDFW also deployed onboard commercial fishing vessel monitoring. All fishermen in the Willapa Bay and Grays Harbor region must attend a Fish Friendly Best Fishing Practices class. Monitoring of commercial fisheries in the Columbia River has occurred annually since 2002 and has increased in scope in recent years. Since January 2004, the California Halibut trawl fishery has carried federal observers who record all green sturgeon encounters, although coverage rates have been fairly limited (Richerson et al. 2019). The Pacific groundfish fisheries are observed at higher rates and data indicate fewer encounters with green sturgeon as compared to the California Halibut fishery (Richerson et al. 2019).

The ESA 4(d) Rule provides an exemption from take prohibitions (not retention) for Southern DPS green sturgeon for commercial and recreational fisheries if those fisheries activities are conducted in accordance with a NMFS-approved Fishery Management and Evaluation Plan (FMEP) (75 FR 30714; June 2, 2010). The FMEP has nine required elements, including setting maximum incidental take levels that will not reduce survival or recovery of the Southern DPS, effective monitoring and evaluation planning, enforcement and education, and reporting of the amount of incidental take on a biannual basis (75 FR 30714; June 2, 2010). Washington has submitted a draft FMEP, which has undergone NMFS review and comment. We will continue to work with Washington to address our comments and finalize the FMEP. We have also coordinated with Oregon and California on development of FMEPs. California is drafting an FMEP and Oregon may submit a plan in the future. As the states develop their FEMPs, we continue to work with them to assess and address green sturgeon bycatch. For example, we have worked with WDFW to monitor green sturgeon habitat use in coastal bays and estuaries to inform fisheries management decisions to minimize bycatch of green sturgeon. We are also working closely with CDFW to evaluate bycatch effects on green sturgeon and develop new ways to reduce bycatch in the California halibut bottom trawl fishery. These efforts will inform the development of the FMEPs.

Since the ESA 4(d) Rule was promulgated in 2010 (75 FR 30714; June 2, 2010), take for scientific purposes has been managed by NMFS under the ESA 4(d) research program and ESA Section 10(a)(1)(A) permits. Authorized take (not retention) of Southern DPS green sturgeon for scientific purposes has been tracked since 2006. In reviewing projects involving Southern DPS green sturgeon, NMFS seeks to minimize the impact of scientific research and maximize the benefits to the species. A protocol for sturgeon research developed by NMFS provides guidelines for all scientific research that involves Southern DPS green sturgeon (Kahn and Mohead 2010). The protocol’s recommendations are designed to minimize stress and potential mortality to sturgeon due to research activities.

In summary, the level of lethal take of Southern DPS green sturgeon has decreased because of state and federal regulations that prohibit their retention in almost all fisheries. Lethal take still occurs as a result of bycatch mortality and a limited number of permitted activities. The impact of lethal take on the overall population abundance of Southern DPS is still being assessed. No estimate of an annual rate of mortality due to poaching has become available since the 2015 review, and therefore, it is still considered a threat.

2.3.2.3 Disease or predation:

Disease was not recognized as a principle factor in listing the Southern DPS due to a lack of sufficient information. Recently, *Chryseobacterium* spp. was detected in one green sturgeon in California waters; however, no potential negative effects of the bacteria were observed (Sebastiao et al. 2019). No new information has become available that changes the conclusion that disease is a principal factor since the listing.

Predation by introduced species was recognized as a possible threat to long-term survival of the Southern DPS. Baird et al. (2020) described the predation rate of juvenile Northern DPS green sturgeon in a laboratory setting using two species introduced to the SFBDE: striped bass and channel catfish. Compared to alternate prey, the predators showed much lower rates of predation on juvenile green sturgeon. Predation decreased with green sturgeon size, and reached zero when green sturgeon were 20-22 cm TL. The predators exhibited low motivation to feed on juvenile green sturgeon (Baird et al. 2020).

Steller sea lions (*Eumetopias jubatus*) are known to feed on sturgeon in the Columbia River. Observations by the U.S. Army Corps of Engineers have recorded only white sturgeon being consumed (Tidwell et al. 2019, Tidwell et al. 2020). In 2009, however, a photograph of a sea lion eating a green sturgeon was taken in the Rogue River. Researchers in Washington and Oregon have also reported puncture wounds and scrapes on North American green sturgeon consistent with pinniped attacks. The previous review stated that CDFW noted predation on Southern DPS green sturgeon by California sea lions (*Zalophus californianus*) in the Sacramento River, bays and Delta. Steller and California sea lion abundance has increased in recent decades (NMFS 2013, Carretta et al. 2018). Southern DPS green sturgeon was collected from the State Water Project's Skinner Delta Fish Protection Facility after a California sea lion attack (Miranda 2018). WDFW has also observed markings on North American green sturgeon that could be consistent with shark attack. A North American green sturgeon was identified in the stomach contents of a white shark captured off Central California (Klimley 1985). The impact of predation on adult and subadult North American green sturgeon is unknown. Although sea lion abundance has increased, there is no new information to support that the threat of predation by sea lions or sharks has changed in severity since the last review.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

The final rule concluded that inadequacy of existing regulatory mechanisms has significantly contributed to the decline of the Southern DPS and to the severity of threats that the species currently faces (71 FR 17757; April 7, 2006). Although there have been improvements to fishing regulations to eliminate harvest and reduce bycatch mortality, and some passage barriers have been removed, less has been accomplished through regulatory mechanisms to reduce other threats (i.e., those posed by still existing migration barriers, water diversions and management). As such, inadequacy of existing regulatory mechanisms regarding Southern DPS green sturgeon habitat remains a high threat.

The 2018 Recovery Plan described regulatory mechanisms that need to be established or improved for Listing Factors A through C and E. For Listing Factor A, regulatory mechanisms need to address sturgeon passage improvement at outstanding barriers to migration (e.g., Sunset Pumps rock weir on the Feather River, Daguerre Point Dam on the Yuba River). Additionally, there should be modifications at impoundment operations and facilities to address flow, water temperature, and sediment impacts for Southern DPS green sturgeon (e.g., Oroville-Thermalito Complex, Keswick Reservoir, Shasta Lake). Lock and gate operations at the Port of Sacramento and Delta Cross Channel also need to be improved. For Listing Factor B, poaching and fishing regulations (e.g., bycatch in state fisheries) need to be enforced. For Listing Factor C, invasive species (e.g., overbite clam) in the SFBDE and Coastal Bays and Estuaries (CBE) need to be controlled. For Listing Factor E, land use regulations for non-point and point source contaminants in the Sacramento River basin and SFBDE need to be enforced. Additionally, response plans for oil and chemical spill in the SFBDE and CBE need to be developed, and offshore and nearshore kinetic energy projects in the CBE and nearshore marine habitat need to be permitted.

Another regulatory mechanism that needs to be established is the development of screen criteria and operations guidelines for agricultural, municipal, and industrial water diversions in the Sacramento River basin and SFBDE. In 2019 and 2020, an interagency group was formed to create a study that would inform screening and passage criteria for sturgeon on the west coast. The group consists of NMFS engineers and biologists, CDFW engineers and biologists, DWR biologists, USACE biologists, and University of California at Davis (UCD) researchers. The Sturgeon Passage Study Plan consists of several modules that will inform criteria for all life stages of green and white sturgeon (Fangue Fish Ecophysiology Laboratory and J. Amorocho Hydraulic Research Laboratory 2020). Modules from this study plan need to be funded to develop screening and passage criteria for Southern DPS green sturgeon.

The Green Sturgeon Habitat, Mitigation, and Monitoring Plan (GS HMMP) team formed to help the USACE implement Southern DPS green sturgeon commitments in the American River Watershed Common Features, West Sacramento, and Sacramento Bank Protection Project biological opinions. These levee projects will likely impact the migratory corridor for several life stages of Southern DPS green sturgeon in the Sacramento River. The GS HMMP team is composed of the USACE, NMFS, and other cooperative agencies as well as green sturgeon experts. The USACE will fund, plan, and implement actions that benefit Southern DPS green sturgeon. This includes a revision of the Standard Assessment Methodology model for green sturgeon, monitoring activities, and mitigation site selection. This strategic implementation plan seeks to ensure that adverse impacts of future bank protection projects on Southern DPS green sturgeon are sufficiently mitigated to allow for the growth, survival, and recovery of the species in areas impacted by USACE projects.

Conservation banks can provide an efficient and effective mechanism to offset adverse effects on listed species and critical habitat and contribute to their conservation. A conservation bank is typically a site that provides ecological functions and services and is conserved and managed in perpetuity for a particular species. Once established, they are later used to compensate for impacts occurring elsewhere to the same species. The value of a bank is defined in compensatory mitigation credits. Credits generated by the bank site are sold by the bank sponsor to parties that need to compensate for the adverse effects of their activities and/or to contribute to the conservation of protected species and their habitats. Compensatory mitigation credits for Southern DPS green sturgeon were not available during the 2015 review. As of this review, a limited amount of Southern DPS green sturgeon credits are available at several conservation banks in the Sacramento River and Delta. Existing conservation banks which provide ecological functional uplift to green sturgeon should develop green sturgeon compensatory mitigation credits to allow project proponents to offset adverse effects to the species. Additionally, new conservation banks should be developed to offer compensatory mitigation credits for habitat functions and services specific to the recovery priorities of green sturgeon.

As stated above in Section 2.3.2.2, the states of California, Oregon, and Washington have enacted regulations to prohibit retention of North American green sturgeon in all commercial and recreational fisheries. Canada has similar regulations in place.

2.3.2.5 Other natural or manmade factors affecting its continued existence:

Non-native species: The final rule did not recognize this as a primary factor in the decline of the Southern DPS. No new data are available on risks posed by non-native species.

Ship Strikes: In early 2020, an interagency team was formed to better understand sturgeon mortality associated with ship strikes. The team is composed of representatives from NMFS, SWFSC, USBR, CDFW, DWR, Delta Stewardship Council, and Cramer Fish Sciences. In April 2018, a white sturgeon mortality from a ship strike was documented in Carquinez Strait (Demetras et al. 2020). Since this reported mortality, other mortality events reported by concerned citizens and local fisheries biologists have occurred. The reports are primarily concentrated in Carquinez Strait, which is a known sturgeon feeding ground and vital migratory corridor to access spawning habitat. The three objectives of the team are: (1) to estimate sturgeon mortality rates in the SFBDE; (2) determine pre-mortality population characteristics, migratory behavior, and habitat use from sampled carcasses; and (3) investigate public perception of sturgeon mortality in the SFBDE. A formal reporting system was introduced in July 2020 with the placement of fliers around the Carquinez Strait asking the public to report any observed sturgeon carcasses to CASturgeonResearch@gmail.com, later changed to CASturgeon.Research@noaa.gov. Along with the report, the public was asked to include photos with a known object for size reference, exact latitude and longitude. As of February 2021, the group has received reports of 23 sturgeon carcasses in the Carquinez Strait from members of the public. Following the reports, scientist collected samples from the reported carcasses. Samples included tissue for genetic confirmation and fin rays to reconstruct age, growth, and migratory history of sturgeon in the SFBDE. These results are not yet available.

Juvenile Entrainment at Unscreened Diversions: In the final rule, the threat posed by juvenile entrainment to the continued existence of the Southern DPS was considered to be uncertain. As stated in the 2015 review, thousands of diversions exist in the Sacramento River and Delta that could potentially entrain Southern DPS green sturgeon (Mussen et al. 2014). Data on entrainment of Southern DPS green sturgeon is limited. Many large diversions (250 cfs and higher) have been screened and projects are planned for screening some smaller diversions (up to 250 cfs) (Vogel 2013). The effectiveness and impact of screening for green sturgeon requires further study given that screen criteria are currently designed to reduce salmon entrainment and impingement (NMFS 2015). For example, Southern DPS green sturgeon spawn upstream and downstream of the Red Bluff Pumping Plant (Poytress et al. 2015), which operates utilizing Chinook salmon screening criteria. Though the diversion facility meets NMFS's screening criteria for salmon, the impact on larval or juvenile Southern DPS green sturgeon that pass this site during some of the highest diversion rates is unknown, and evaluation of screening criteria in regard to green sturgeon is needed. Experimental modules developed by UCD (see Section 2.3.2.4) will inform screening criteria for larval and juvenile green sturgeon. These studies need to be funded to provide screening and operations criteria for sturgeon on the west coast.

As noted in the 2015 review, laboratory experiments indicate that young-of-year juvenile green sturgeon contact screens and become impinged upon them more frequently than similarly-sized white sturgeon (Poletto et al. 2014a). Deterrent treatments (e.g., acoustic vibrations, strobe lights) did not reduce the number of impingements for either species (Poletto et al. 2014a). The long-term impact of repeated impingement has not been studied. Young-of-year juvenile green sturgeon are highly vulnerable to entrainment through unscreened diversion pipes, and water diversion rates impact entrainment with lower diversion rates resulting in lower entrainment rates (Mussen et al. 2014). Poletto et al. (2014b) found that when sturgeon were exposed to sweeping velocities and diversion rates similar to operation flows that entrainment rates were significantly reduced with the use of terminal pipe plates and upturned pipe plates. Strobe lights did not significantly reduced entrainment rates for sturgeon in these scenarios. Poletto et al. (2014b) recommended installation of terminal pipe plates as the more feasible way to reduce entrainment. Further study is needed to understand changes associated with ontogeny and to define conditions where fish are most susceptible, so as to better apply the findings to conservation of the Southern DPS within the river and estuary environment.

A better understanding of the threat posed by unscreened diversions could be gathered by comparing when and where vulnerable stages of Southern DPS green sturgeon (e.g., eggs or newly emerged) occur in the river with the location and operation of unscreened diversions that may be diverting at critical locations during critical periods. Limited field data exist on entrainment of the Southern DPS green sturgeon in unscreened diversions. See the 2015 review for further information regarding field data. A laboratory flow study recommends that water diversion flows should be limited to 29 cm/s at water diversion structures in the upper and middle reaches of the Sacramento River from May through the summer (Verhille et al. 2014). In the middle reaches of the Sacramento River, the maximal velocity should be 54 cm/s during the night from July until the following May. During October and November, maximal diversion velocities should not exceed 40 cm/s in the middle and lower reaches of the Sacramento River and the Delta and Bays (Verhille et al. 2014).

As stated in the 2015 review, entrainment rates of green sturgeon at Tracy Fish Collection Facility and the Skinner Delta Fish Protective Facility in the South Delta have decreased since 1986 (Adams et al. 2002, BRT 2005, Adams et al. 2007). Salvage data from the Tracy Fish Collection Facility and Skinner Delta Fish Protective Facility for the period from January 2016 to July 2020 indicates that few Southern DPS green sturgeon are encountered at the facilities. Southern DPS green sturgeon encounters by year are as follows (observed number, estimated number salvaged): 2016: 1, 4; 2017: 1, 4; 2020: 2, 8 (DWR 2020 database https://apps.wildlife.ca.gov/Salvage/). In comparison to the 2015 review, salvage was much lower at the facilities from 2016-2020. The USFWS Delta Juvenile Fish Monitoring Program did not encounter any green sturgeon during beach seines and trawl surveys from 2012 to 2020. However, CDFW has captured over 140 juvenile green sturgeon in the Delta from 2016-2020 (Beccio 2020). Surveys in Grays Harbor and Willapa Bay (2020) report captures of over 120 green sturgeon (Heironimus 2021b). The reviewed information suggests that the number of green sturgeon entrained remains low.

Contaminants: Since the 2015 review, the application of the chemical pesticides carbaryl and imidacloprid to control burrowing shrimp (i.e., ghost shrimp (*Neotrypaea californiensis*) and mud shrimp (*Upogebia pugettensis*)) populations in Washington estuaries has been banned. The use of carbaryl, and its control of burrowing shrimp and mud shrimp, poses a threat to North American green sturgeon. Since green sturgeon feed on burrowing shrimp, a potential negative impact from carbaryl application may occur, but little is known about the nature of this impact (Dumbauld et al. 2008). Exposure to carbaryl also may make green sturgeon more vulnerable to predation (NMFS 2009b). The chemical carbaryl was used to remove the threat of burrowing shrimp to oyster aquaculture in Willapa Bay and Grays Harbor. The chemical imidacloprid, a proposed alternative to carbaryl, was slated to come into use in 2015, but the use of imidacloprid was prohibited by the Ecology Department of Washington state in 2019 (Willapa-Grays Harbor Oyster Growers Assocation v. State of Washington, Department of Ecology and Ad Hoc Coalition for Willapa Bay, Center for Food Safety, Center for Biological Diversity, and Coaltion to Protect Puget Sound; October 15, 2019). Imidacloprid is less toxic than carbaryl to fish (Frew et al. 2015, Troiano and Grue 2016). Studies show that green sturgeon will opportunistically feed on burrowing shrimp that have been exposed to imidacloprid, which would result in exposure to imidacloprid through consumption of contaminated shrimp as well as the sediment porewater (Frew et al. 2015). No sublethal effects of imidacloprid were observed during exposure studies on surrogate white sturgeon (Frew and Grue 2015). Carbaryl is also used in Central Valley agriculture, which may make green sturgeon more vulnerable to predation, but its full effects on green sturgeon have not been studied.

Selenium contamination in San Francisco Bay, San Pablo Bay, and Suisun Bay continues to pose a potential threat to Southern DPS green sturgeon because green sturgeon feed on benthic invertebrates, including the Asian clam (*Corbula amurensis)*, which is an effective bioaccumulator. As stated in the 2015 review, yolk sac larvae of green sturgeon are more sensitive to selenium than those of white sturgeon (USFWS 2012). Although larval green sturgeon are not found in the SFBDE, the impact of selenium on larval green sturgeon informs current knowledge of how selenium affects the species. Using a regression approach and data from white sturgeon as a proxy, USFWS (2012) calculated selenium concentrations in the tissue and diet of green sturgeon and offered benchmark selenium concentrations in different life stages. Adverse effects on green sturgeon including significant mortality and reduced growth rate was observed when exposed to L-Selenomethionine (Se-Met), a common natural food source of selenium, at levels in the range of selenium levels reported in the benthic macro-vertebrate community of San Francisco Bay (De Riu et al. 2014). Exposure had a more severe pathological effect on green sturgeon as compared to white sturgeon (De Riu et al. 2014). De Riu et al. (2014) concluded that white sturgeon is a poor surrogate model for green sturgeon dietary Se-Met toxicity.

Other contaminants impacting green sturgeon were observed in laboratory and field studies. Laboratory experiments in which green sturgeon were exposed to dietary methylmercury indicate that green sturgeon are more susceptible to being adversely affected by dietary methylmercury as compared to white sturgeon as evidenced by higher mortality and lower growth rates (Lee et al. 2011). A blood plasma study of wild green sturgeon in Washington estuaries observed that most frequently detected contaminants included Aldrin, 4,4,-DDE, a-BHC, copper and selenium (Layshock et al. In press.). Layshock et al. (In press.) found that fish caught in the most urbanized sites had the highest contaminant loads. The study did not find any significant difference in contaminant load based on sex, age, or maturity, or population. No additional information is available on the impacts of other chemicals, pesticides, or heavy metals on Southern DPS green sturgeon.

Climate Change: Climate change has the potential to impact Southern DPS green sturgeon in the future, but it is unclear how changing oceanic, nearshore, and river conditions will affect the Southern DPS overall. In freshwater environments (e.g., Sacramento River system), water flow and temperature are important factors influencing Southern DPS green sturgeon spawning and recruitment success (see Section 2.3.1.1). Climate change models predict increased runoff in the winter with reduced spring flows over the course of the 21st century (CH2M HILL 2014, NMFS 2019). Reservoir operations will also be impacted by climate change, with reservoirs filling up earlier and excess water being released to ensure flood control capacity. These changes in water temperature and flow in the Sacramento, Feather, and Yuba rivers may impact the timing and success of Southern DPS green sturgeon spawning.

It is difficult to predict how the Southern DPS may respond to these changing conditions and how climate change impacts in the nearshore and estuarine environment will also impact spawning timing and success. For example, ambient water temperature modeled under the Proposed Action of the Long-Term Operations of the Central Valley Project and State Water Project may exceed suitable levels (>17°C) during the critical egg fertilization and incubation period in the majority of years at the downstream extent of the spawning reach near Hamilton City, California (NMFS 2019). Klimley et al. (2020) modeled the impact of flows on habitat suitability within three known spawning areas in the Sacramento River. In years of low discharge (2012 to 2015 drought conditions), the amount of suitable spawning habitat was reduced in one of three locations (Klimley et al. 2020). Diminished flows in dry years may impact Southern DPS spawning habitat. As stated in the 2015 review, the salinity in the Sacramento River is projected to increase by 33%, on average, by the end of the 21st century (CH2M HILL 2014). This will result in declining habitat quality and food web productivity, which will likely impact the health of green sturgeon subadults. Laboratory experiments confirm the potential negative impacts of salinity and prey base changes predicted for the SFBDE on green sturgeon (Sardella and Kultz 2014, Haller et al. 2015, Vaz et al. 2015). Similar climate change induced habitat quality impacts in estuaries in Washington and Oregon could affect the health of subadult and non-spawning adult Southern DPS green sturgeon. The prey base for the Southern DPS could be further impacted by ocean acidification. Changing ocean conditions could also impact Southern DPS green sturgeon since subadults and adults use ocean habitats for migration and potentially for feeding. Based on their use of coastal bay and estuarine habitats, subadults and adults can occupy habitats with a wide range of temperature, salinity, and dissolved oxygen levels, so predicting the impact of climate change in these environments is difficult (Kelly et al. 2007, Moser and Lindley 2007).

Rodgers et al. (2019) analyzed the mean effects of elevated temperatures, salinity, low food availability, and contaminants on growth as well as thermal tolerance, swimming performance, and heat shock protein expression. All variables significantly impaired green sturgeon growth. Elevated water temperature increased heat shock protein expressions and deformities while decreasing hatchling success. Salinity increased plasma osmolality and muscle moisture. Food restriction only affected growth. Contaminants increased mortality and body burden. Rodgers et al. (2019) suggested conservation measures such as mitigating salt intrusion in nursery habitats and maintaining water temperatures within optimal ranges during peak spawning periods. Overall, our knowledge of the environmental impact of climate change is increasing, but the direction of the impact on the Southern DPS is unknown at this point in time. Further research on the impact of climate change (multiple stressors) on embryonic, yolk-sac larvae, and post yolk-sac larvae needs to occur. Monitoring potential impacts into the future is important for population recovery.

Kinetic Energy Projects: An emerging threat is the development and operation of offshore and near shore kinetic energy projects. Impacts of such projects on green sturgeon could involve direct mortality or habitat loss and sensitivity to low levels of electromagnetic fields associated with the operations that could impact migration and habitat use (Nelson et al. 2008, Normandeau et al. 2011, NMFS 2018). Another concern is the potential effect on green sturgeon from the use of turbines at the mouths of large rivers (e.g., just upstream of the Golden Gate Bridge in San Francisco Bay). The effect of electromagnetic fields from a high voltage, direct current cable leading from Pittsburg, California to San Francisco, California has been studied based on detections of acoustically tagged green sturgeon before and after the cable was installed in 2010 (Klimley et al. 2017). Cable activity did not impact overall successful movement of green sturgeon through the area. However, additional research is needed regarding this threat, including examining the response of green sturgeon to different levels of electromagnetic fields. It should be noted that the permitting process for these facilities considers potential Southern DPS effects and monitoring may be a requirement for any facility receiving a permit.

Summary: In summary, no new information is available regarding the threats posed by non-native species. While efforts have been made to screen large diversions (>250 cfs), entrainment into smaller diversions still poses a threat to Southern DPS green sturgeon. No changes in NMFS or CDFW screen criteria have been made since the last review. Screening and facility operation criteria needs to be developed for green sturgeon. Carbaryl and imidacloprid have been phased out, but a new chemical may be used in its place in the future, which could impact the Southern DPS. Selenium is still likely a threat to the Southern DPS.

The threat of climate change and ocean acidification to Southern DPS green sturgeon cannot be measured using the available information, but changing freshwater and nearshore environments could impact Southern DPS green sturgeon health, spawning, and recruitment. The emerging threat posed by nearshore and offshore energy development requires continued attention into the future. The threats covered in this section are numerous. Overall, the new information does not support a conclusion that the threats have increased in severity since the last review, but many of the threats require close attention into the future.

2.4 Synthesis

The DPS structure of the North American green sturgeon has not changed since the last review. The Southern DPS occupies the same range as originally defined. Southern DPS spawning primarily occurs in the mainstem Sacramento River. Spawning has also been confirmed in the Feather and Yuba rivers in some years at low levels, relative to the spawning that occurs in the Sacramento River. The spatial structure of Southern DPS green sturgeon within the Sacramento River and in coastal environments is now better defined. Limited occupancy within the Sacramento River is concerning, and trends in this pattern and the number of individual green sturgeon present in the river should be monitored into the future. Protective measures instituted by CDFW to prohibit any sturgeon fishing where Southern DPS green sturgeon reproduce are important and should be maintained.

Many of the principal factors considered when listing Southern DPS green sturgeon as threatened are relatively unchanged. Recent studies confirm that the spawning area utilized by Southern DPS green sturgeon is small. Confirmation of spawning in the Feather and Yuba rivers is encouraging and the decommissioning of RBDD and the breach of Shanghai Bend makes spawning conditions more favorable, although Southern DPS green sturgeon still encounter impassable barriers in the Sacramento, Feather, and Yuba rivers that limit their spawning range. Improving fish passage at Fremont Weir is also encouraging for subadult and adult survival by reducing entrainment and potential poaching due to entrainment on floodplains (Seesholtz 2020). The relationship between altered flows and temperatures in spawning and rearing habitat and Southern DPS green sturgeon population productivity is uncertain. Entrainment, as well as stranding in flood diversions during high water events, also negatively impact Southern DPS green sturgeon. The prohibition of retention in commercial and recreational fisheries has eliminated a known threat and likely had a very positive effect on the overall population, although recruitment indices are not presently available.

The 2018 Recovery Plan developed five demographic criteria for recovery of Southern DPS green sturgeon. Since there were no reliable estimates of historical or current Southern DPS green sturgeon abundance, adult abundance criteria was developed using the best available information from general principles in conservation biology relating population viability to abundance (NMFS 2018). Continued annual DIDSON surveys are needed to track Southern DPS green sturgeon spawning populations into the future.

Additional future work utilizing this and other data sources (Beamesderfer et al. 2007) to look at abundance within a modeling framework would be useful and could provide a baseline for understanding the population-level impact of various sources of Southern DPS green sturgeon “take” authorized under the ESA 4(d). Studies measuring fisheries bycatch mortality by gear type would assist in measuring the impact of bycatch of Southern DPS green sturgeon in state and federal fisheries. Information gathered through the FMEP process will assist in understanding and limiting fisheries impacts.

Evaluation of new information since the 2015 review does not suggest a significant change in the status of Southern DPS green sturgeon. With respect to threats, the available information indicates that some threats, such as those posed by fisheries and impassable barriers, have been reduced. The threat of climate change on all life stages of green sturgeon persists, but requires continued research. The emerging threat posed by nearshore and offshore energy development requires continued attention into the future. Since the majority of the threats cited in the original listing still exist, the Threatened status is still applicable.

3.0 RESULTS

3.1 Recommended Classification

Given your responses to previous sections, particularly section 2.4. Synthesis, make a recommendation with regard to the listing classification of the species

_____**Downlist to Threatened**
_____**Uplist to Endangered**
_____**Delist** *(Indicate reason for delisting per 50 CFR 424.11):*
_____*Extinction*
_____*Recovery*
_____*Original data for classification in error*
X____**No change is needed**

3.2 New Recovery Priority Number

No change

Brief Rationale:

3.3 Listing and Reclassification Priority Number

Reclassification (from Threatened to Endangered) Priority Number: ____
Reclassification (from Endangered to Threatened) Priority Number: ____
Delisting (Removal from list regardless of current classification) Priority Number: ____

Brief Rationale:

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

The Recovery Plan for the Southern DPS of the North American Green Sturgeon was completed in August 2018. The Recovery Plan outlines specific recovery actions, research priorities, monitoring priorities, and education and outreach priorities for Southern DPS Green Sturgeon. Actions and Priorities within the plan are ranked. Actions stemming from this review that would assist in improving the status of and available information about Southern DPS green sturgeon are as follows:

1. Continue monitoring and studying key life history stages and modeling population abundance. Long-term monitoring is needed to develop temperature and flow targets in accessible spawning, incubation, and rearing habitats. Research is needed on the impact of habitat modification and/or restoration (e.g., levee alteration, floodplain connectivity) on green sturgeon recruitment and growth and water management on green sturgeon habitat, as well as growth and survival. Increased acoustic tagging and monitoring for all life stages of green sturgeon is needed throughout its range but especially within the Sacramento River basin and SFBDE. Continued funding for a core acoustic telemetry array is highly recommended. Acoustic monitoring for green sturgeon needs to be expanded to South San Francisco Bay to better understand habitat use and foraging of subadults. Also, greater monitoring for juvenile green sturgeon is needed in the lower estuary to better understand juvenile green sturgeon habitat use of the SFBDE. Monitoring for green sturgeon in the San Joaquin River basin using eDNA, telemetry, and other sampling methods (i.e., fyke trap, hook-n-line) should be increased.
2. Continue efforts to remove barriers to migration and improve fish passage so that Southern DPS green sturgeon can reach spawning grounds and to reduce entrainment on floodplains. Upstream passage above the boulder weir located at Sunset Pumps in the Feather River is needed so that Southern DPS green sturgeon will be able to access spawning grounds. Structural improvements to Fremont Weir (Yolo Bypass) and Tisdale Weir (Sutter Bypass) need to be made to reduce stranding and provide passage. In addition to fish passage improvements at Yolo and Sutter bypasses, adaptive management plans should be developed with green sturgeon experts to reduce any further entrainment of sturgeon. Fish passage for Southern DPS green sturgeon needs to be developed at Daguerre Point Dam on the Yuba River. Removing this barrier will likely provide greater access to suitable spawning habitat for Southern DPS green sturgeon. Further research is needed to determine the impact of the Sacramento Deep Water Ship Channel and Port of Sacramento on upstream migration of green sturgeon. Research is also needed to determine the impact on the operations of the Delta Cross Channel gates on green sturgeon migration.
3. Continue efforts to reduce entrainment of juvenile green sturgeon at water diversions with the development of screening and fish passage criteria. First, all current and proposed water diversions posing a risk to green sturgeon need to be identified. Second, operation and screening guidelines need to be developed for green sturgeon. The modules outlined in the UCD Sturgeon Study Plan provide experiments that will develop criteria based on swimming performance metrics, attraction flows, and fishway interaction for all

life stages of green sturgeon. Once criteria is developed, it should be applied in the mainstem Sacramento, Feather, and Yuba rivers as well as the SFBDE to reduce early life stage entrainment. Climate change and sea level rise should also be addressed by the screening and passage criteria.

4. Continue efforts to reduce take from poaching and fisheries bycatch. There should be an increased enforcement presence at Yolo and Sutter bypasses when overtopping events occur to prevent poaching events. Relocation efforts of green sturgeon from entrainment on floodplains by CDFW should continue to occur with passage improvement at Fremont and Tisdale weirs. Further research is needed to estimate the annual level of mortality of Southern DPS green sturgeon from poaching. An outreach program for law enforcement personnel, fishing guides, and fishermen should be developed to inform them of the green sturgeon protections under the ESA as well as potential problems of post-release mortality and poaching. The FMEPs for state fisheries encountering Southern DPS green sturgeon also need to be completed. Research on green sturgeon mortality from incidental capture in fisheries (e.g., gillnet, hook-n-line, coastal trawling) should continue to occur. Research on green sturgeon interaction with commercial fishing gear should also continue to occur. Estimating mortality from poaching and fisheries bycatch is needed to inform population estimates for Southern DPS green sturgeon.
5. Continued research of the impact of contaminants, disease, predation, and climate change on all life stages of green sturgeon should occur. More data is needed to inform natural resource managers about these threats to Southern DPS green sturgeon recovery.

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NATIONAL MARINE FISHERIES SERVICE
5-YEAR REVIEW
Southern Distinct Population Segment of the North American Green Sturgeon
(*Acipenser medirostris*)

Current Classification: Threatened

Recommendation resulting from the 5-Year Review

____ Downlist to Threatened
____ Uplist to Endangered
____ Delist
X___ No change is needed

Review Conducted By:

National Marine Fisheries Service, West Coast Region, California Central Valley Office

REGIONAL OFFICE APPROVAL:

Lead Regional Administrator, NOAA Fisheries

Approve____ Date: October 26, 2021

The Lead Region must ensure that other Regions within the range of the species have been provided adequate opportunity to review and comment prior to the review's completion. Written concurrence from other regions is required.

HEADQUARTERS APPROVAL:

Assistant Administrator, NOAA Fisheries

__X___Concur _____ Do Not Concur

Signature RAUCH.SAMUEL.D.III.1365850948 Digitally signed by RAUCH.SAMUEL.D.III.1365850948 Date: 2021.10.28 10:47:38 -04'00' Date_______