Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon (*Acipenser medirostris*)

Sacramento River Green Sturgeon. Credit: M. Manuel

2018

Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon
(*Acipenser medirostris*)

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Approved: ______________________________
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List of Acronyms and Abbreviations

ACID	Anderson–Cottonwood Irrigation District
ADEC	Alaska Department of Environmental Conservation
Army Corps	United States Army Corps of Engineers
BMP	Best Management Practice
BRT	Biological Review Team
C	Celsius
CBE	Coastal Bays and Estuaries
CDFG	California Department of Fish and Game (up to 12-31-2012)
CDFW	California Department of Fish and Wildlife (aka CDFG prior to 2013)
CDWR	California Department of Water Resources
cfs	Cubic feet per second
CALFED	California Federal Bay-Delta Program
CVPIA	Central Valley Project Improvement Act
DIDSON	Dual Frequency Identification Sonar
dph	Days post hatch
DPS	Distinct Population Segment
EMF	Electromagnetic fields
EPA	United States Environmental Protection Agency
ESA	Endangered Species Act
FERC	Federal Energy Regulatory Commission
FMEP	Fishery Management Evaluation Plan
FR	Federal Register
GCID	Glenn Colusa Irrigation District
nDPS	Northern Distinct Population Segment
NM	Nearshore Marine
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
Oregon DEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
PCBs	Polychlorinated Biphenyls
PCE	Primary Constituent Element
RBDD	Red Bluff Diversion Dam
rkm	River Kilometer
sDPS	Southern Distinct Population Segment
SFBDE	San Francisco Bay Delta Estuary
SRB	Sacramento River Basin
SWP	State Water Project
TCD	Temperature Control Device
TL	Total Length
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WDOE	Washington Department of Ecology
WDFW	Washington Department of Fish and Wildlife

Executive Summary

Species Status

The southern distinct population segment (sDPS) of North American green sturgeon *(Acipenser medirostris)* is an anadromous, long-lived, late maturing species that spawns in the Sacramento River Basin, located in the Central Valley of California. It spends most of its life in the nearshore marine environment and coastal bays and estuaries along the west coast of North America. On April 7, 2006, NMFS listed sDPS green sturgeon as a threatened species under the Endangered Species Act (ESA) (71 FR 17757, April 7, 2006). This determination was based on the fact that the Sacramento River basin contains the only known sDPS spawning population, information suggesting population decline, and habitat loss and degradation in the Sacramento River Basin. Since the listing of the sDPS, a number of habitat restoration actions within the Sacramento River Basin have occurred and spawning has been documented in the Feather and Yuba rivers (Seesholtz et al. 2015; Beccio 2018), but many significant threats have not been addressed. Currently, the majority of sDPS green sturgeon spawning occurs within a single reach of the mainstem Sacramento River, placing the species at increased risk of extinction due to stochastic events.

Recovery Goal, Objective, and Criteria

The goal of this recovery plan is to recover sDPS green sturgeon and consequently remove it from the Federal List of Endangered and Threatened Wildlife. Achieving this goal will have a number of economic, societal, and ecosystem benefits. Delisting of the sDPS may result in opening fisheries that were closed due to direct or incidental sDPS mortality, resulting in economic and recreational benefits. The ESA regulatory burden will also be eased for fisheries, water resource, industrial, and commercial activities. Accomplishing the habitat restoration measures will also result in more functional ecosystems that support other economic activities and contribute to the conservation and recovery of other species.

To achieve delisting, the objective of this recovery plan is to increase sDPS green sturgeon abundance, distribution, productivity, and diversity by alleviating significant threats. To determine when these threats have been alleviated and the sDPS green sturgeon population has recovered, the following criteria have been developed:

Demographic Recovery Criteria

1. The adult sDPS 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 be comprised of a combined total, from all spawning locations, of at least 500 adult fish in any given year.
2. sDPS 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.

3. A net positive trend in juvenile and subadult abundance is observed over the course of at least 20 years.
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).
5. There is no net loss of sDPS green sturgeon diversity[3] from current levels.

Threat-Based Recovery Criteria

1. Access to spawning habitat is improved through barrier removal or modification in the Sacramento, Feather, and/or Yuba rivers such that successful spawning occurs annually in at least two rivers. Successful spawning will be determined by the annual presence of larvae for at least 20 years.
2. Volitional passage is provided for adult green sturgeon through the Yolo and Sutter bypasses.
3. Water temperature and flows are provided in spawning habitat such that juvenile recruitment is documented annually. Recruitment is determined by the annual presence of age-0 juveniles in the lower Sacramento River or San Francisco Bay Delta Estuary. Flow and temperature guidelines have been derived from analysis of inter-annual spawning and recruitment success and are informing this criterion.
4. Adult contaminant levels are below levels that are identified as limiting population maintenance and growth.
5. Operation guidelines and/or fish screens are applied to water diversions in mainstem Sacramento, Feather, and Yuba rivers and San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment.
6. Take of adults and subadults through poaching and state, federal and tribal fisheries is minimal and does not limit population persistence and growth.

Recovery Strategy & Actions

In order to recover sDPS green sturgeon, 20 recovery actions are presented that aim to restore passage and habitat, reduce mortality from fisheries, entrainment, and poaching, and address threats in the areas of contaminants, climate change, predation, sediment loading and oil and chemical spills. Most of the recovery efforts focus on the Sacramento River Basin and San Francisco Bay Delta Estuary environments, as threats in spawning and rearing habitats were considered the greatest impediments to recovery. Seventeen priority recovery actions aim to incrementally restore habitat below Keswick, Oroville, and Englebright dams, provide volitional passage upstream of the boulder weir at Sunset Pumps on the Feather River and at Daguerre Point Dam on the Yuba River, support adequate water flow and temperature on the Sacramento, Feather, and Yuba rivers now and in the future, reduce stranding at Yolo and Sutter bypasses and other sources of take (e.g., fisheries bycatch), improve rearing habitats in the San Francisco Bay Delta Estuary, and ameliorate the risk posed by entrainment in water

[3] Diversity refers to variation in life history, behavior, age structure, genetics, and physiology. Our current understanding of sDPS green sturgeon diversity is described in this recovery plan and published literature (e.g., Israel et al. 2004: Lindley et al. 2008, 2011; Anderson et al. 2017).

diversions and contaminants. An additional three recovery actions address predation and non-point source sediment loading. These actions will likely have less of a direct and immediate impact in terms of meeting the recovery criteria and are thus considered secondary in priority.

The recovery strategy calls for simultaneous implementation of research, monitoring, and education and outreach programs. The 16 research priorities identified focus on the same recovery action topics discussed above as well as competition for habitat, altered prey base, non-native species, and disease. The monitoring program focuses on demonstrating attainment of demographic and threat-based recovery criteria, tracking the effectiveness of recovery actions, and filling critical data gaps in the life history of sDPS green sturgeon. The education and outreach program seeks to gain public and agency partner support and facilitate recovery plan implementation. Working with partners to secure funding for implementing this recovery plan is also an essential component of the plan.

Estimated Date and Cost of Recovery

Based on the identified recovery actions, the estimated cost for the first 20 years of implementation is $237 million. Many of the most-costly recovery actions (e.g., barrier removal, increased enforcement, addressing entrainment at diversions) have multi-species benefits and may be covered under recovery efforts for other species. For example, the recovery plan for ESA-listed Central Valley salmonids (NMFS 2014) includes recovery actions designed to improve watershed-wide processes that will likely benefit sDPS green sturgeon by restoring natural ecosystem functions. Specific actions to improve Delta habitat, remove barriers, and reduce entrainment could aid in the recovery of the sDPS green sturgeon and reduce the recovery plan cost by $17 million.

It is anticipated that the recovery of sDPS green sturgeon is likely to be a long process. Restoring habitat by providing adequate water flow and temperature and addressing migration barriers is likely to take ten years or more. Due to green sturgeon’s slow maturation and low recruitment rate, increases in abundance may not be observed for three to four generations following habitat improvement. Given a generation time for sDPS green sturgeon of approximately 22 years, a substantial increase in adult abundance in response to habitat-based recovery actions may not be observed for 66-88 years. Funds will thus likely be needed to monitor adult abundance after the first 20 years, for a total additional overall cost of $25-40 million. Additional funds may also be needed to monitor larval, juvenile, and subadult life stages in order to meet the demographic criteria.

Chapter I. Background

The purpose of this recovery document is to guide implementation of the recovery of the southern Distinct Population Segment (sDPS) of North American green sturgeon (*Acipenser medirostris*). Section 4(f) of the Endangered Species Act (ESA) directs NOAA's National Marine Fisheries Service (NMFS) to develop and implement recovery plans for threatened and endangered species, unless such a plan would not promote conservation of the species. The recovery recommendations detailed herein aim to resolve the main threats to the sDPS and ensure self-sustaining populations in the wild into the future.

Status of the Species

On April 7, 2006, NMFS determined that the sDPS warranted listing as a threatened species (71 FR 17757), effective July 6, 2006. This determination was based on: (1) the fact that the spawning adult population occurred in only one river system (i.e., Sacramento River); (2) evidence of lost spawning habitat in the Sacramento and Feather rivers; (3) threats to habitat quality and quantity in the Sacramento River and Delta System; and (4) fish salvage data exhibiting a negative trend in juvenile sDPS abundance. The sDPS was assigned a recovery priority number of 5 under the ESA on a scale of 0-10 under the current guidance (i.e., 55 FR 24296, June 15, 1990). A priority number of 5 indicates a moderate risk of extinction. The priority number reflects the presence of factors that may limit sDPS recovery such as conflicting uses of water within its habitat (e.g., agriculture, urban) as detailed in this document. The recovery potential for this species is likely high, however, if sources of mortality and activities that decrease habitat quality and quantity, particularly in spawning and rearing habitat, are limited.

Description and Taxonomy

The North American green sturgeon is one of 27 species of sturgeon within the Order Acipenseriformes and Family Acipenseridae (Billard and Lecointre 2000). Part of the Class of bony fishes (Osteichthyes), sturgeons are unique in having a mostly cartilaginous skeleton and having scutes covering their bodies rather than scales. All sturgeons inhabit the Northern Hemisphere, reproduce in freshwater, and are characterized by late maturity and a long lifespan. Most species are benthic feeders. Many sturgeons are of conservation concern due to historical overfishing, poaching, and/or spawning habitat degradation and loss.

The North American green sturgeon was first described by Ayres (1854) based on a specimen from San Francisco Bay. The species was once considered to be conspecific with the Russian Far East Sakhalin sturgeon (*A. mikadoi*), but genetic differences later confirmed the species as distinct (Birstein and Bemis 1997). Green sturgeon share the west coast of North America with the white sturgeon, *A. transmontanus* (Moyle 2002), and may be distinguished from this sympatric sturgeon by their olive green color, barbel placement (closer to the mouth than the tip of their snout), a prominent green stripe on the lateral and ventral sides of their abdomen, the number of dorsal and lateral scutes, the presence of one large scute behind the dorsal and anal fins (which is absent in white sturgeon), and the location of the vent (North et al. 2002; Figure 1).

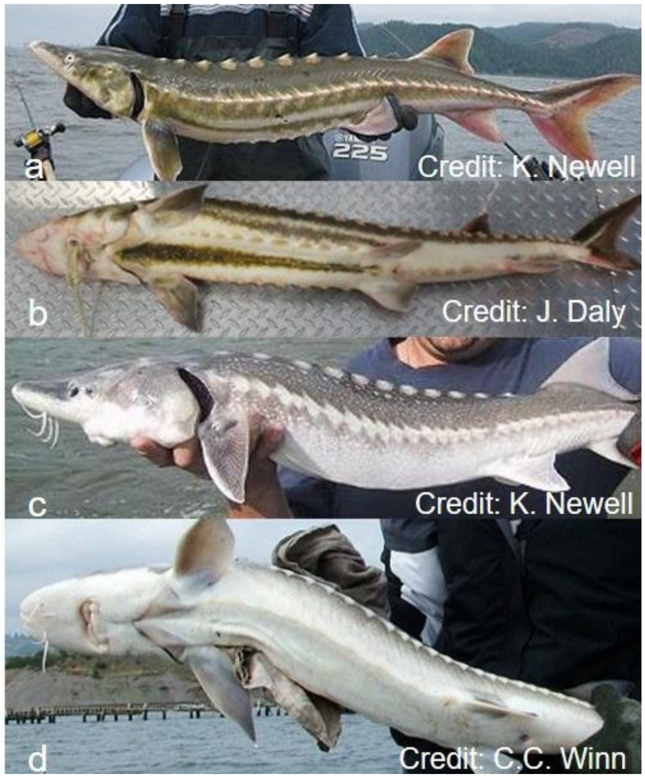

Figure 1. Green sturgeon morphological differences. Lateral and ventral morphological differences between green sturgeon (a-b) and white sturgeon (c-d).

Two distinct population segments are recognized within the North American green sturgeon based on genetic information and spawning site fidelity: the sDPS and a northern DPS (nDPS) of green sturgeon (68 FR 4433, January 23, 2003; Adams et al. 2002; Israel et al. 2004). The sDPS of green sturgeon spawns in the Sacramento River basin. The nDPS of green sturgeon spawns in the Rogue River in southern Oregon and the Klamath River in northern California. Recent genetic analysis of samples from five non-juvenile green sturgeon collected in the Eel River confirms assignment of the Eel River population to the nDPS (Anderson et al. 2017). Recent study also suggests a spawning population in the Eel River (Stillwater Sciences and Wiyot Tribe Natural Resources Department 2017). In the Columbia River, both juvenile and spermiating adult green sturgeon have been documented (Langness 2005; Schreier et al. 2016). One juvenile collected in the Columbia River in 2011 was assigned to the nDPS (Schreier et al. 2016), but additional DPS assignments were unavailable at the time of writing. The nDPS and sDPS inhabit similar estuarine and marine habitats along the west coast and are morphologically similar; genetic analysis is the only method currently available to identify them to DPS in these habitats. The nDPS is considered a NMFS Species of Concern (http://www.nmfs.noaa.gov/pr/species/concern/).

Population Trends

Several challenges exist in understanding population trends in sDPS green sturgeon. Sturgeon catch in California was not historically reported by species and green sturgeon harvest in other areas probably included mixtures of nDPS and sDPS fish. At present, the most useful dataset for examining population trends comes from Dual Frequency Identification Sonar (DIDSON) surveys in the Sacramento River, which began in 2010. These surveys have been used to estimate the abundance of sDPS adults at 2,106 individuals (95% confidence interval [CI] = 1,246-2,966; Mora 2016; Mora et al. 2018). A conceptual demographic structure applied to that adult population estimate resulted in an sDPS subadult population estimate of 11,055 (95% CI = 6,540-15,571) (Mora et al. 2018). The DIDSON surveys and associated modeling will eventually provide population trend data. Other efforts to track population trends are underway using tagging and fisheries data and larval capture as reviewed in Heublein et al. (2017a).

Distribution

The sDPS of the anadromous green sturgeon occurs along the western seaboard of North America (Figures 2 and 3). Non-spawning adult and subadult nDPS and sDPS green sturgeon spend much of their lives coexisting in marine and estuarine waters from the Bering Sea, Alaska (Colway and Stevenson 2007) to El Socorro, Baja California, Mexico (Rosales-Casian and Almeda-Juaregui 2009). Telemetry, genetic, and fisheries data suggest that sDPS green sturgeon generally occur from Graves Harbor, Alaska to Monterey Bay, California (Moser and Lindley 2007; Lindley et al. 2008, 2011; Schreier et al. 2016) and, within this range, frequent coastal waters of Washington, Oregon, Vancouver Island, and San Francisco and Monterey bays (Huff et al. 2012). Adult and subadult sDPS green sturgeon occur in relatively large concentrations from late spring to autumn within coastal bays and estuaries including the Columbia River estuary, Willapa Bay, Grays Harbor and the Umpqua River estuary, with peaks in abundance in summer and autumn (Moser and Lindley 2007; Lindley et al. 2011; WDFW and ODFW 2012; Schreier et al. 2016; Hansel et al. 2017). Green sturgeon have been detected in acoustic tagging surveys within the Chehalis River (off Grays Harbor; 2004-2005 study), but the detected sturgeon were not assigned to a DPS (Langness 2007). Within the nearshore marine environment, sDPS green sturgeon most often inhabit marine waters less than 110 m in depth (Erickson and Hightower 2007). Although the nDPS and sDPS coexist in the marine environment, the two DPSs only enter spawning areas of their respective natal rivers (Lindley et al. 2011).

Within the freshwater portion of their range, sDPS distribution is limited by permanent or flow-dependent barriers (Figures 3-6; Mora et al. 2009). Keswick Dam (rkm 486, completed in 1950), Shasta Dam (rkm 505, completed in 1944), and Fremont Weir and Sutter Bypass/Tisdale Weir (both flow-dependent) on the Sacramento River, and Oroville Dam (rkm 116, completed in 1968) on the Feather River are impassible barriers (71 FR 17757, April 7, 2006). Potential barriers to adult migration also include the Sacramento Deep Water Ship Channel locks, the Anderson Cottonwood Irrigation District Dam (ACID; rkm 479, completed in 1937; typically operated from April through October), the Delta Cross Channel Gates on the Sacramento River, and Sunset Pumps (rkm 39, originally completed in 1800s, reconfigured in 2003) on the Feather River (BRT 2005; 71 FR 17757, April 7, 2006). The Fish Barrier Dam (rkm 108.5, completed in 1964) on the Feather River and the Daguerre Point Dam (rkm 19, completed in 1910) on the lower Yuba River are also recognized as limiting the distribution of the sDPS (74 FR 52300, October 9, 2009; Mora et al. 2009). Additional potential barriers on the Feather River include Thermalito Diversion Dam (rkm 109, completed in 1968). On the Sacramento, features such as scour pools, borrow pits, and swales within bypasses can also potentially strand green sturgeon when bypass flooding flows recede. Two barriers originally cited in the listing decision as posing a limit to distribution have undergone changes since the listing: Red Bluff Diversion Dam (RBDD; rkm 391, completed 1964) on the Sacramento River and Shanghai Bend on the Feather River. The decommissioning of RBDD in 2013 now permits passage of the sDPS during all months that they are present in the river. The breach of Shanghai Bend on the Feather River in early 2012 likely also eliminated this naturally-formed passage barrier (flow-dependent) in the lower Feather River (NMFS 2015).

The Sacramento River watershed is the only confirmed historical and present spawning area for the sDPS (Adams et al. 2007). Within the Sacramento River, the sDPS spawns from the GCID area (rkm 332.5) to Cow Creek (rkm 451) based on adult distribution (Heublein et al. 2009; Klimley et al. 2015a; Mora et al. 2018), with egg mat sampling confirming spawning between the GCID area and Inks Creek (rkm 426) (Poytress et al. 2015). Adults, eggs, and larvae can occur in the latter area during spawning and rearing periods. Spawning at the Thermalito Afterbay Outlet in the Feather River was first documented in June 2011 (Seesholtz et al. 2015) by the presence of fertilized eggs collected from egg mats and was coincident with the above average flows during a wet year. Adult sturgeon have been detected in other areas in the Feather River (i.e., from the Fish Barrier Dam to Shanghai Bend), but aside from the Thermalito Afterbay Outlet, spawning has only been confirmed in one year (2017) at the Fish Barrier Dam. Green sturgeon have been observed in the lower Yuba River downstream of Daguerre Point Dam as recently as 2018 (Cramer Fish Sciences 2011; Heublein et al. 2017a; Kurth 2018). Spawning immediately below Daguerre Point Dam was documented in 2018 (Beccio 2018).

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

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

Presumed sDPS green sturgeon have also been documented in other tributaries and river systems. Data from angler self-reporting indicate catch of green sturgeon in the San Joaquin River and of subadult green sturgeon in the Napa River (DuBois et al. 2014; DuBois and Harris 2015, 2016; DuBois and Danos 2017). Spawning could have been supported in the San Joaquin River based on the habitat that existed in this system historically (Adams et al. 2007; Mora et al. 2009), but spawning has not been documented historically or currently. Sightings of green sturgeon have also been recorded in the Bear River (USFWS 1995; Beamesderfer et al. 2004). Although sturgeon have been observed in the Russian River, the only known photo is of a white sturgeon. The American, Stanislaus, and Tuolumne rivers may have historically supported the sDPS based on habitat attributes, but no confirmed green sturgeon sightings exist (Beamesderfer et al. 2004) with the exception of recent confirmation of a green sturgeon in the Stanislaus (Martarano 2018).

Life History/Habitat Requirements

As noted above, green sturgeon use riverine, estuarine, and marine habitats along the west coast of North America, spending substantial portions of their lives in marine waters (Erickson and Hightower 2007; Lindley et al. 2008, 2011). Green sturgeon are long lived (54 years, Nakamoto et al. 1995), late maturing (around 15 years of age, Van Eenennaam et al. 2006) and exhibit spawning site fidelity in natal streams (Poytress et al. 2011). After maturity is reached at approximately 15 years of age and 150 cm total length, the sDPS typically spawn every three to four years (range two to six years) (Brown 2007; Poytress et al. 2012; NMFS 2015). Adult sDPS enter San Francisco Bay in late winter through early spring and spawn in the Sacramento River primarily from April through early July, with peaks of activity likely influenced by factors including water flow and temperature (Heublein et al. 2009; Poytress et al. 2011, 2015). Late summer or early fall spawning may also occur given presence of sDPS larvae in October 1997, 1999 and 2000 at GCID and the fall of 2016 at RBDD. In the nDPS, temperature seems to be an important cue signaling adults to migrate into river systems (Erickson and Webb 2007). Water flow is an important cue in spawning migration for both nDPS and sDPS green sturgeon, with outmigration related to elevated flows (Benson et al. 2007; Erickson and Webb 2007; Heublein et al. 2009; Poytress et al. 2011, 2012; University of California at Davis, unpublished data). In white sturgeon, spawning has been documented to occur after elevated flows (Schaffter 1997; Jackson et al. 2016), suggesting a connection between flow and spawning.

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

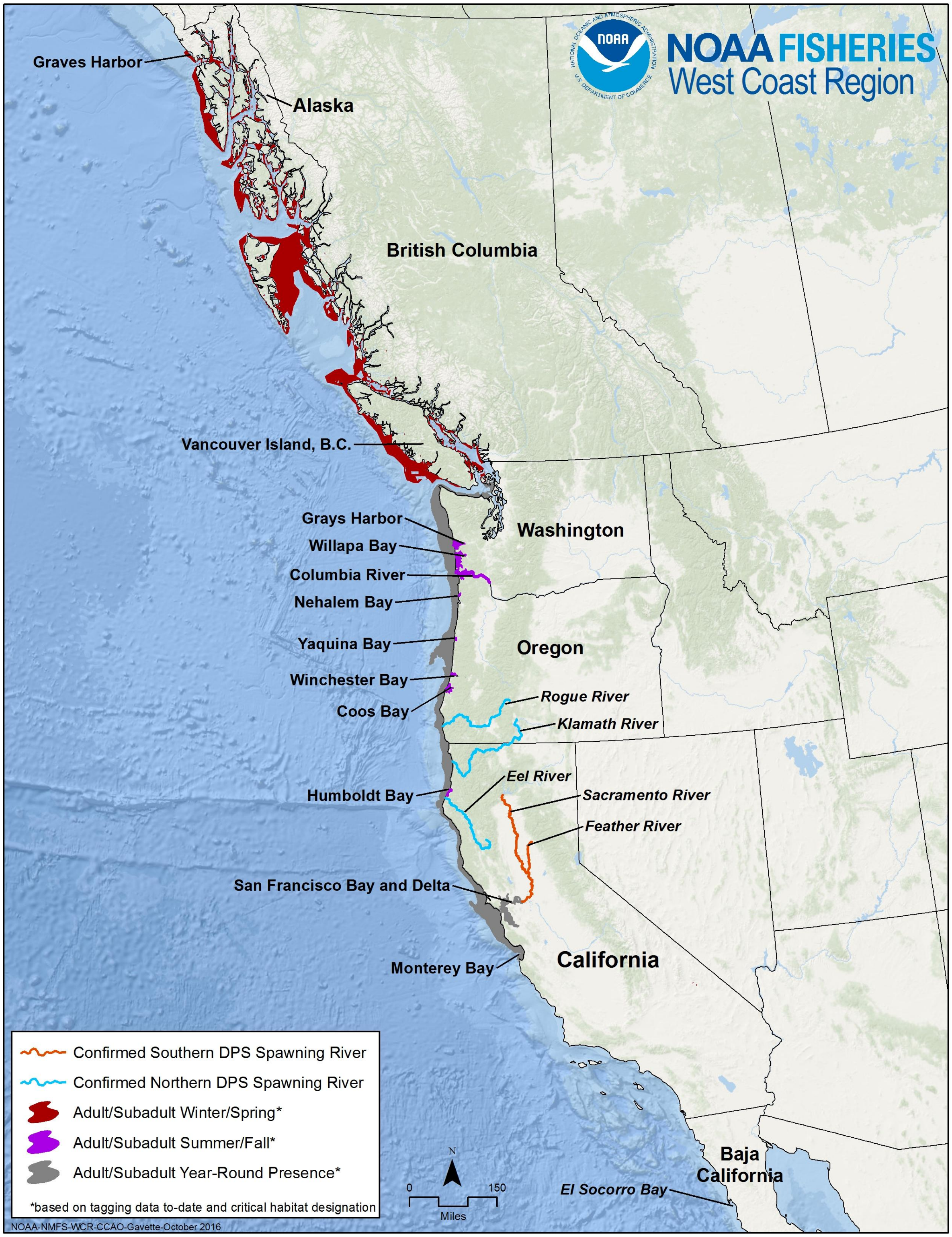

Figure 2. Map of west coast of North America showing distribution of adult and subadult sDPS green sturgeon.

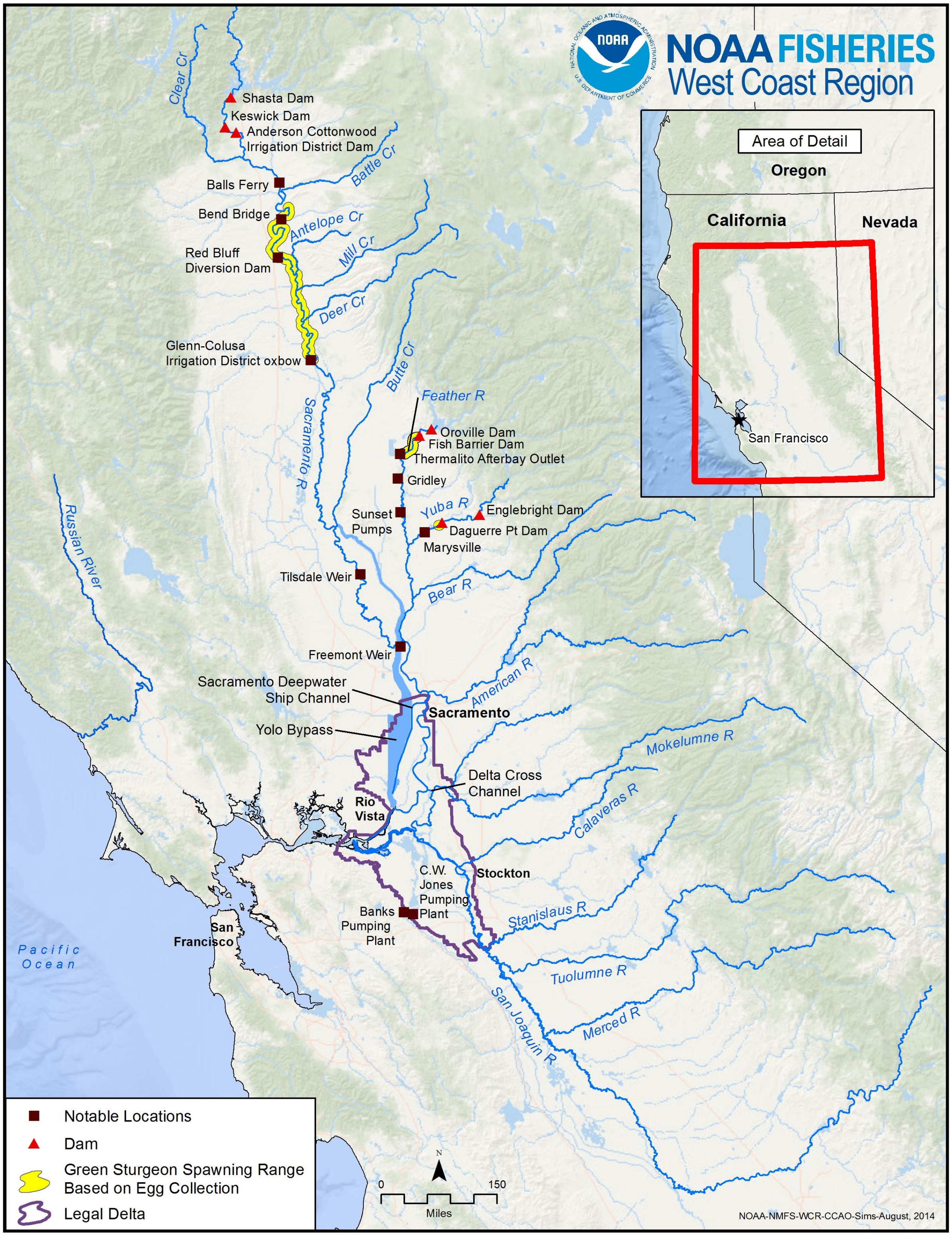

Figure 3. Map of California's Central Valley showing distribution of sDPS green sturgeon.

Figure 4. Migration barriers for the sDPS on the Sacramento mainstem: (a) Shasta Dam, Source: USBR; (b) Keswick Dam, Source: USBR; (c) Anderson-Cottonwood Irrigation District flash dam, Source: Bill Paxson.

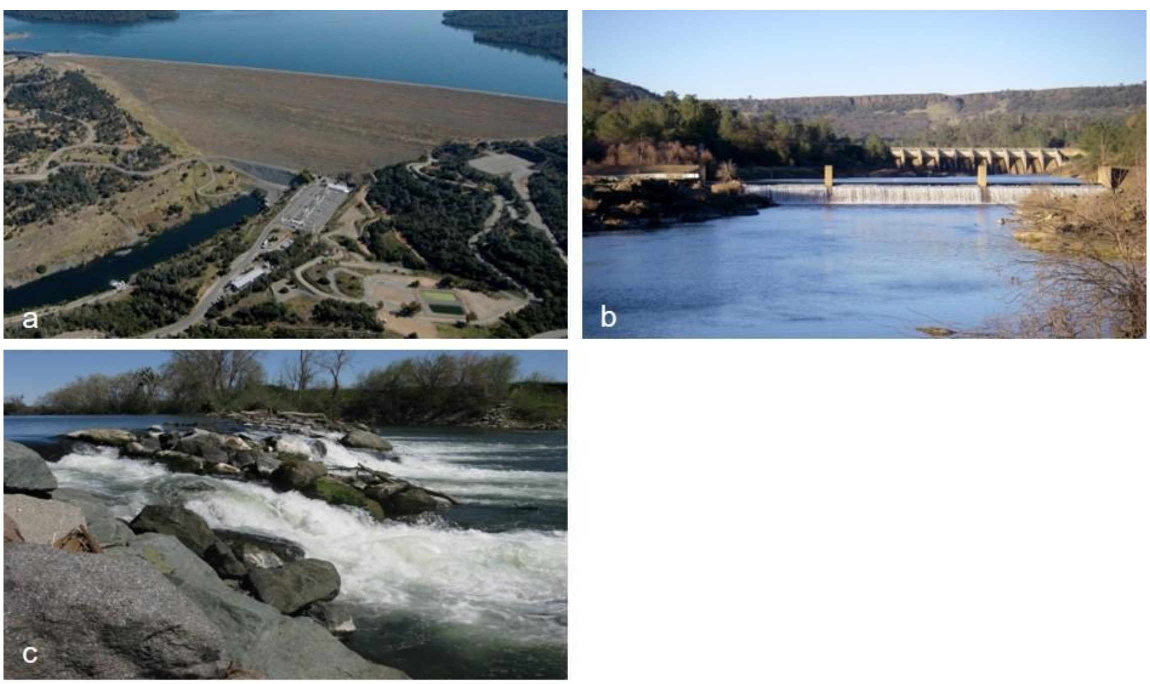

Figure 5. Migration barriers for the sDPS on the Feather River: (a) Oroville Dam, Source: CDFW; (b) Thermalito Diversion Dam (background) and Fish Barrier Dam (foreground), Source: Thomas O'Keefe; (c) Boulder weir at Sunset Pumps, Source: Alicia Seesholtz.

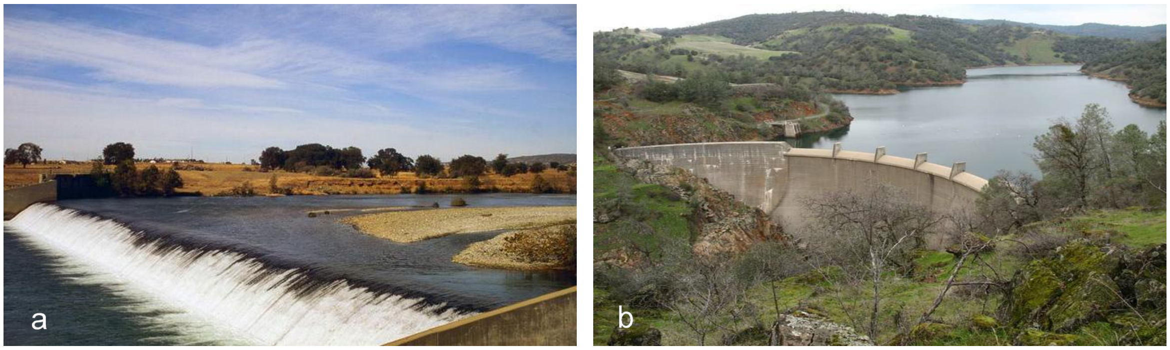

Figure 6. Migration barriers for the sDPS on the Yuba River: (a) Daguerre Point Dam, Source: Hank Meals; (b) Englebright Dam, Source: Hank Meals.

The early life history of the sDPS has not been fully studied, so data from experiments using the nDPS are used as a proxy for the sDPS life history and habitat requirements. Three recent documents give full descriptions of these data (NMFS 2015; Moser et al. 2016; Heublein et al. 2017a) and can be referenced for additional information. Green sturgeon eggs primarily adhere to gravel or cobble substrates or settle into crevices (Van Eenennaam et al. 2001; Poytress et al. 2011). Lab-based data from the nDPS indicate that eggs hatch after 144-192 hours when incubated at a temperature of 15.7 ± 0.2°C (Deng et al. 2002). Temperature plays a role in egg development according to laboratory studies and is likely a factor in sDPS recovery. Van Eenennaam et al. (2005) found that the hatching rate for green sturgeon eggs was slightly reduced when incubation temperatures were less than 11°C. They also found that the upper lethal temperature for developing embryos was 22-23°C, with sub-lethal effects occurring at 17.5 to 22.2°C (Van Eenennaam et al. 2005).

Green sturgeon larvae disperse at approximately 12 days post hatch (dph) in the laboratory (Kynard et al. 2005). Larval activity is primarily nocturnal, with peaks in migration between dusk and dawn (Kynard et al. 2005; Poytress et al. 2011). Larvae utilize benthic structure (Van Eenennaam et al. 2001; Deng et al. 2002; Kynard et al. 2005) and seek refuge within crevices but will forage over hard surfaces (Nguyen and Crocker 2007). Larval abundance and distribution may be influenced by spring and summer outflow and recruitment may be highest in wet years, making water flow an important habitat parameter (reviewed in Heublein et al. 2017a). California Department of Fish and Game (CDFG 1992) and USFWS (1995) found a positive correlation between mean daily freshwater outflow (April to July) and white sturgeon year class strength in the San Francisco Bay Delta Estuary. These studies involved the more abundant white sturgeon, which has life history requirements similar to those of green sturgeon. This correlation is consistent with relationships found for other anadromous fish in the estuary and may be due to the fact that flows transport larvae to areas with greater food availability, disperse larvae over a wider area, or enhance nutrient availability.

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

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

The subadult life stage begins at the first entry into the Pacific Ocean and extends until maturity is reached. When not in rivers for spawning, adults and subadults migrate seasonally along the coast and congregate in nearshore marine waters as described in the Distribution section above. Tagging studies indicate that green sturgeon typically occupy depths of 20-70 m in marine environments (Erickson and Hightower 2007; Huff et al. 2011) making rapid vertical ascents, often at night (Erickson and Hightower 2007). Temperatures occupied in the marine environment range from 7.3-16°C, with a range of mean temperatures from 10.5-12.5 °C (Erickson and Hightower 2007; Huff et al. 2011). In the estuarine environment, green sturgeon are exposed to varying water temperatures, salinities, and dissolved oxygen (DO) concentrations. For example, green sturgeon in coastal estuaries have been detected in water temperatures ranging from 11.9-21.9°C, salinities from 8.8-32.1 parts per thousand, and DO from 6.54 to 8.98 milligrams of oxygen per liter (Kelly et al. 2007; Moser and Lindley 2007).

Green sturgeon are opportunistic feeders that consume a variety of prey items. The diet of larval green sturgeon is unknown but may be similar to that of larval white sturgeon, which includes macrobenthic invertebrates such as insect larvae, oligochaetes, and decapods (NMFS 2009a). In the San Francisco Bay Delta Estuary, juvenile green sturgeon feed on shrimp, amphipods, isopods, clams, annelid worms, and an assortment of crabs and fish (Ganssle 1966; Radtke 1966). Post-spawn adult green sturgeon in freshwater likely feed on benthic prey species (e.g., lamprey ammocoetes, crayfish). In coastal bays and estuaries, adult and subadult green sturgeon feed on shrimp, clams, crabs, and benthic fish (Moyle et al. 1995; Dumbauld et al. 2008). Nearshore marine prey resources likely include species similar to those of coastal bays and estuaries. Recent stomach content data from subadult green sturgeon captured in the California halibut trawl fishery indicate a diet consisting mostly of right-eyed flatfish (likely English sole *Parophrys vetulus*), followed by shrimp (Palanidae), bivalves (likely Macoma spp.), and crab (Cancer spp.) (R. Bellmer, CDFW, unpublished).

Reasons for Listing

The habitat for the sDPS in California's Central Valley has been modified since the mid-19th century (Lockington 1879). Degradation of sDPS habitat has occurred due to hydraulic gold mining (1860s to early 1900s) and associated continued mercury contamination of sediments as well as alteration of wetland habitats to create farmland (1850s to 1930s). Since the 1950s, construction of water pumping plants, dams and water diversions (Figure 7) has altered the hydrograph and habitats of the Sacramento River watershed and created barriers to migration. More recently, urbanization has resulted in increasing demands for water as well as the alteration of large areas of aquatic and riparian habitat.

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

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

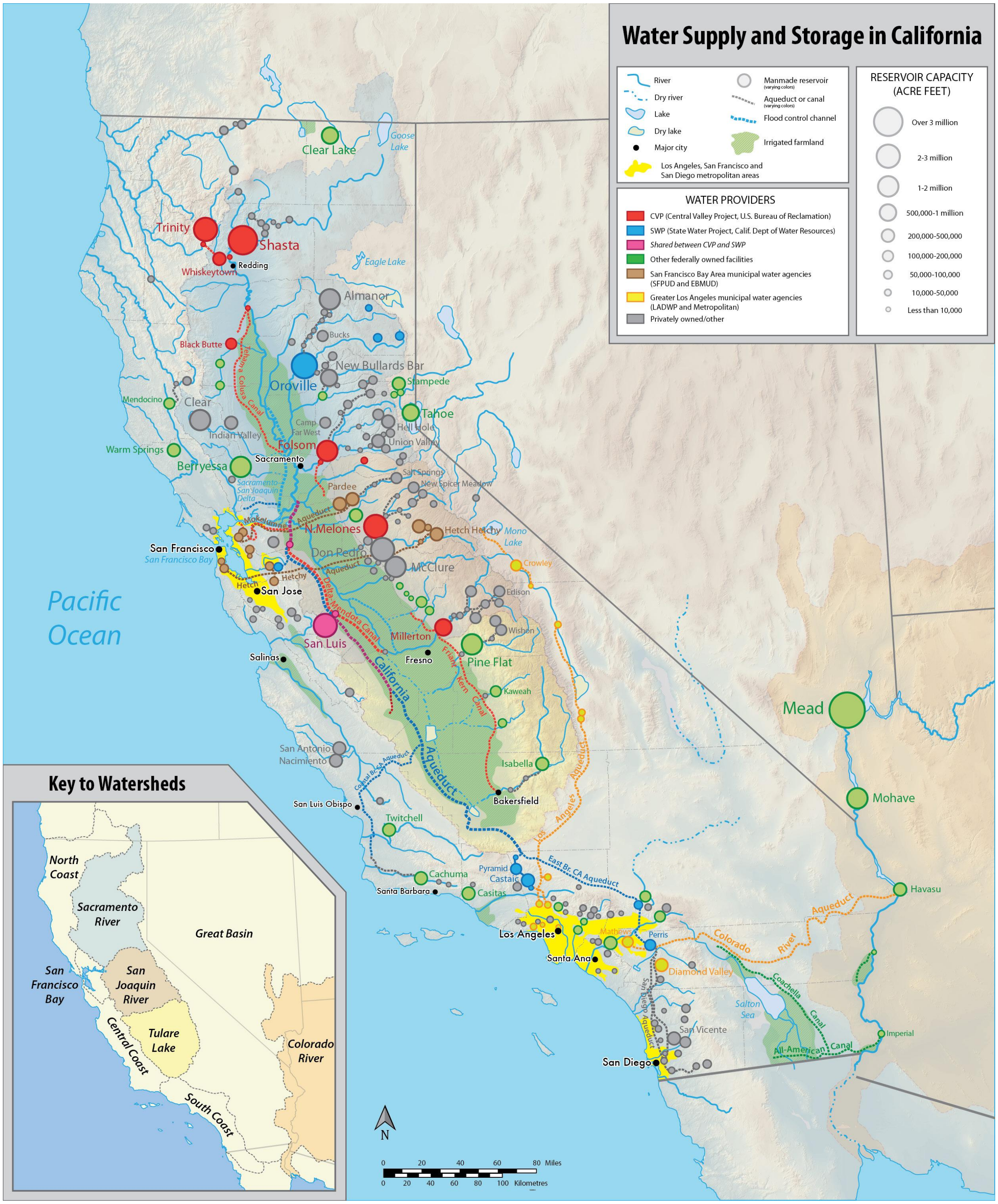

Figure 7. Map of water storage and delivery facilities as well as major rivers and cities in the state of California. Project systems are in red, and State Water Project in blue. Source: Wikipedia.

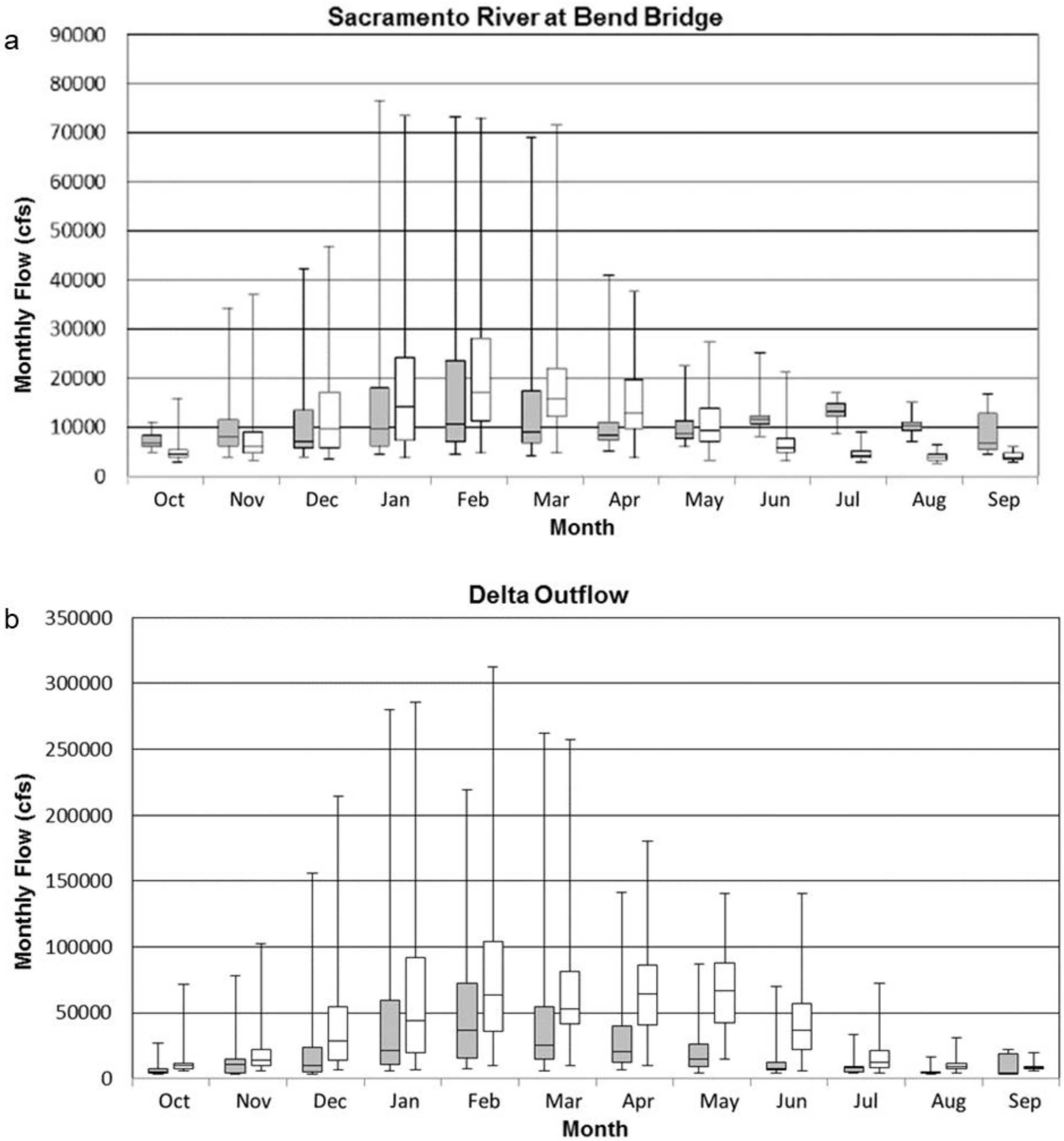

Figure 8. Adapted from Figure 2.2-2 (a) and 2.4-6 (b) in Sacramento Water Resources Control Board (2016). Boxplot summarizing monthly current hydrologic conditions (gray box) and unimpaired flow (white box) at Bend Bridge on the Sacramento River (a) and (b) for simulated delta net outflow. Plot shows maximum and minimum flows (top and bottom whiskers), upper quartile (top of box), median (line within box) and lower quartile (bottom of box) of the flow data.

Critical Habitat

On October 9, 2009, NMFS published a final rule designating critical habitat for sDPS green sturgeon (74 FR 52300, October 9, 2009) pursuant to 50 CFR 424.12(b). The designation took effect on November 9, 2009 (Figure 9).

Figure 9. Map of critical habitat for the sDPS. Refer to text for more specific location information.

The essential features of the sDPS critical habitat are as follows:

Freshwater riverine systems:

a) Food resources. Abundant prey items for larval, juvenile, subadult, and adult life stages.
b) Substrate type or size (i.e., structural features of substrates). Substrates suitable for egg deposition and development (e.g., bedrock sills and shelves, cobble and gravel, or hard clean sand, with interstices or irregular surfaces to “collect” eggs and provide protection from predators, and free of excessive silt and debris that could smother eggs during incubation), larval development (e.g., substrates with interstices or voids providing refuge from predators and from high flow conditions), and feeding of juveniles, subadults, and adults (e.g., sand/mud substrates).
c) Water flow. A flow regime (i.e., the magnitude, frequency, duration, seasonality, and rate-of-change of fresh water discharge over time) necessary for normal behavior, growth, and survival of all life stages.
d) Water quality. Water quality, including temperature, salinity, oxygen content, and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages.
e) Migratory corridor. A migratory pathway necessary for the safe and timely passage of all life stages within riverine habitats and between riverine and estuarine habitats (e.g., an unobstructed river or dammed river that still allows for safe and timely passage).
f) Depth. Deep ($\geq$ 5 m) holding pools for both upstream and downstream holding of adult or subadult fish, with adequate water quality and flow to maintain the physiological needs of the holding adult or subadult fish.
g) Sediment quality. Sediment quality (i.e., chemical characteristics) necessary for normal behavior, growth, and viability of all life stages.

For estuarine habitats:

a) Food resources. Abundant prey items within estuarine habitats and substrates for juvenile, subadult, and adult life stages.
b) Water flow. Within bays and estuaries adjacent to the Sacramento River (i.e., the Sacramento-San Joaquin Delta and the Suisun, San Pablo, and San Francisco bays), sufficient flow into the bay and estuary to allow adults to successfully orient to the incoming flow and migrate upstream to spawning grounds.
c) Water quality. Water quality, including temperature, salinity, oxygen content, and other chemical characteristics, necessary for normal behavior, growth, and viability of all life stages.
d) Migratory corridor. A migratory pathway necessary for the safe and timely passage of all life stages within estuarine habitats and between estuarine and riverine or marine habitats.
e) Depth. A diversity of depths necessary for shelter, foraging, and migration of juvenile, subadult, and adult life stages.
f) Sediment quality. Sediment quality (i.e., chemical characteristics) necessary for normal behavior, growth, and viability of all life stages.

For nearshore coastal marine areas:

a) Migratory corridor. A migratory pathway necessary for the safe and timely passage of all life stages within marine and between estuarine and marine habitats.
b) Water quality. Nearshore marine waters with adequate DO levels and low enough levels of contaminants (e.g., pesticides, organochlorines, elevated levels of heavy metals) to allow normal behavior, growth, and viability of subadult and adult green sturgeon.
c) Food resources. Abundant prey items for subadults and adults, which may include benthic invertebrate fishes.

Threats Assessment

In 2010-2011, the sDPS green sturgeon Recovery Team conducted a threats assessment to reevaluate the threats affecting green sturgeon to provide the basis for a recovery plan. Appendix A describes the methodology used to conduct the threats assessment for each habitat unit and the definitions for each specific threat for each threat category for each habitat. In 2015, the Recovery Team reconvened to discuss the recovery plan draft and concluded that the threats assessment was still current.

The Recovery Team ranked threats across the following habitat units and life stages: 1) Sacramento River Basin (SRB; Sacramento River and its tributaries) – adults, eggs, larvae, juveniles; 2) San Francisco Bay Delta Estuary (SFBDE; tidal waters inland of the Golden Gate Bridge and the legal boundaries of the Delta as defined in California Water Code Section 12220) – adults, subadults, juveniles; 3) Coastal Bays and Estuaries (CBE; the bays and estuaries along the west coast (mainly from Grays Harbor south to Monterey Bay, but excluding SFBDE) – adults, subadults; and 4) Nearshore Marine (NM; nearshore waters (shore to a depth of approximately 110 m from Alaska to mid Baja California, Mexico)) – adults, subadults. Life stages are defined as: 1) eggs from release to hatching, 2) larvae hatched from eggs until complete metamorphosis (1 to 6 centimeters [cm] total length [TL]), 3) juveniles from complete metamorphosis until their first entry to the ocean (6 to 65 cm TL), 4) sub-adults from first ocean entry to first spawning (65 to 150 cm TL), and 5) adults that are sexually mature and fish greater than 150 cm

Current and future threats were considered following guidelines developed under Conservation Measures Partnership and Benetech's Miradi program (Website Address is: https://miradi.org/). Threats were classified as "Very High, High, Medium, Low, or Not Applicable" and based on the "scope, severity, and permanence" of the threat (see Appendix A for more detail). Although data sufficiency was not used to derive a final ranking for each threat, it was considered in reference to each threat and is detailed in Table 1. It should be noted that threats were ranked within habitat units only, and sometimes relative to other threats within the same habitat unit, in terms of their severity. Thus, threat rankings within each habitat unit are relative to that habitat unit only rather than in comparison across habitat units. When preparing to allocate limited resources to recovery, stakeholders should recognize that additional work would be required to compare threats across habitat units. A Very High or High score for scope/severity or for permanence also had a large influence on the overall rating. Many threats in the CBE and NM were influenced by these factors, particularly because permanence was ranked highly, even though data sufficiency was ranked low. These factors were considered when deciding whether a threat should be addressed through a research priority or recovery action. In some cases, insufficient information about a Very High or High ranking threat prevented the development of a recovery action, so a research priority was developed instead. This additional research could improve our understanding of a threat, refine threat ranking, and lead to the development of a research action.

The conclusion reached by the Recovery Team following their threats assessment was that the primary threats identified at the time of listing were still present, although no new evidence suggested a decline in abundance. Most of the assessed threats were given a Low or Medium ranking, with 24 of the 87 threats ranked High or Very High for any habitat unit or life stage within a unit (Table 1). However, for many of the threats ranked High or Very High, the level of data sufficiency regarding the threat and its effects on the species was low (Table 1). In other words, the Recovery Team felt that these threats could have substantial impacts on the species, but also expressed a high degree of uncertainty regarding these threats, either due to a lack of understanding about the species or the threat itself. For some of these threats, research priorities rather than recovery actions were developed. The only threat ranked as High or Very High that also had a high degree of data sufficiency was that of impoundments causing a barrier to migration in the SRB.

Recovery actions (Chapter III, IV) are provided for most threats ranked Very High or High as well as some that were ranked Medium or Low, because new information indicates that the threat may substantially affect the sDPS. For example, following the threats assessment, new information became available regarding entrainment risk to green sturgeon (Mussen et al. 2014). The Recovery Team's threats assessment does not reflect this new study, but the plan's recovery actions include a measure to address this threat. As stated above, some threats ranked as Very High or High were not assigned a recovery action, due to low data sufficiency and/or limited current understanding of the threat, the impact of scope, permanence, or geographic area on the overall ranking, or some combination of these factors.

Threats to sDPS Green Sturgeon (Organized by the Five ESA Listing Factors)

The narrative below provides a description of the threats identified by the Recovery Team based on the five listing factors described in ESA section 4(a)(1) that need to be addressed in order to promote recovery of the sDPS.

Listing Factor A - Destruction, Modification, or Curtailment of Habitat or Range

The majority of the threats examined by the Recovery Team and most of the threats ranked as Very High were in this Listing Factor category. Major threats ranked as High or Very High include altered water flow, prey base, water temperatures, water quality (including turbidity) and depth, and sediments. As in the original listing, barriers to migration were also recognized as a considerable threat. Additional threats included contaminants and loss of wetland function.

Altered Water Flow

Within the SFBDE, channel control structures, impoundments, and upstream diversions were recognized as specific threats that have altered and impacted juvenile and subadult/adult sDPS green sturgeon. The SFBDE environment has been highly impacted by structures built to divert water and by upstream impoundments, which have changed flow patterns, channel morphology, and water depth/presence and salinity in certain areas. Localized flow patterns can impact habitat quality for the sDPS and flow may impact migration and movement. Data sufficiency was low in terms of the impact of altered water flow in the SFBDE.

Altered water flow was ranked as a Medium to Low threat within the SRB. A discussion of the impact of altered flow as a barrier to migration can be found in the corresponding section below. As indicated in sections above, flow may be a migration cue for green sturgeon, so altered flows could impact in or out migration. Flows could also impact the number of deep pools in the river as well as those with specific characteristics (possibly including flow) that are necessary for spawning. Flow is also likely important for egg development and larval dispersal, but specific, appropriate flow rates are not determined. Reduced spring flows could negatively impact recruitment, given the likely relationship between high spring flows and high sDPS green sturgeon recruitment seen in 2006 (Heublein et al. 2017a). Successful spawning in the Feather River has also been linked to high spring flows (2011 and 2017; Heublein et al. 2017a). Under existing regulated conditions on the Feather River, the high spring flows that appear to be necessary for green sturgeon spawning are extremely rare. In light of this new information, altered water flow may be greater than a Medium to Low threat to recovery in the SRB.

Within the CBE, altered flow due to impoundments was ranked High, with medium data sufficiency. Relatively large numbers of sDPS green sturgeon seasonally utilize the following bays and estuaries: 1) Humboldt Bay in California; 2) Coos, Winchester (Umpqua River estuary), Yaquina, and Nehalem bays in Oregon; 3) Willapa Bay and Grays Harbor in Washington; and 4) the lower Columbia River estuary from the mouth to river kilometer 74 (the SFBDE is discussed separately). Of the CBEs listed, the Columbia River estuary has the most significant alterations to unimpaired flow related to impoundments. In this case, water management operations hold back water during spring and early summer compared to pre-development condition, thereby reducing flows in the estuary. This can affect salinity intrusion and other water quality parameters. sDPS subadults and adults would likely be able to find areas of suitable water quality but foraging habitat may be affected by factors associated with altered flow. Additional studies are needed to understand the relationship between flow and foraging habitat across the CBE (e.g., in the Nehalem, Umpqua and other important estuaries) as well as how flows and salinity intrusion may be impacted by climate change and sea level rise.

Table 1. Results of the Recovery Team assessment in ranking threats across habitat units with associated data sufficiency. See main text and Appendix A for more details. Note: Listing Factor D “Inadequacy of existing regulatory mechanisms” was addressed for each specific threat under listing factors A through C and E. Blank categories (grey cells) indicate specific threats that were not selected for rating (described in greater detail in Appendix A). Specific threats ranked Very High and High are highlighted in red and yellow, respectively.

Listing Factor	Threat Category	Specific Threat	Sacramento River Basin					
			Eggs	Data Sufficiency	Larvae/ Juveniles	Data Sufficiency	Adults	Data Sufficiency
A. Habitat Destruction, Modification, or Curtailment	Altered Water Flow	Channel control structures	Medium	Low	Medium	Low	Low	Medium
		Impoundments	Medium	Low	Low	Low	Medium	Medium
		Upstream Diversions	Low	Low	Low	Low	Low	Low
		Local Diversions	Medium	Low	Medium	Low	Medium	Low
		Bypasses			Low	Low	Medium	Low
	Altered Prey Base	Non-native species			High	Low	Medium	Low
		Global climate change			High	Low	Medium	Low
		Non-point source contaminants			Medium	Low	Medium	Low
		Point source contaminants			Medium	Low	Low	Low
		Harvest of prey species					Low	Low
		Dredging and disposal or dredged materials			Low	Low	Low	Low
	Altered Water Temperature	Global climate change	Medium	Low	High	Low	High	Low
		Impoundments	High	Medium	High	Medium	Medium	Medium
		Sacramento River temperature management	Medium	Medium	Medium	Medium	Medium	Medium
		Local diversions	Medium	Medium	Medium	Medium	Medium	Medium
		Point source thermal effluent	Medium	Low	Medium	Low	Low	Low
		Bypasses			Medium	Low	Medium	Low
		Non-point source thermal effluent	Low	Low	Medium	Low	Low	Low
	Contaminants	Non-point source contaminants	High	Medium	High	Medium	High	Medium
		Point source contaminants	High	Medium	High	Medium	High	Medium
		Dredging and disposal of dredged material	Low	Low	Low	Low	Low	Low
		In-water construction	Low	Low	Low	Low	Low	Low
	Altered Sediment	Impoundments	Medium	Low	Medium	Low	Medium	Medium
		Non-point source sediment	Medium	Low	Medium	Low	Medium	Low
		Channel control structures	Medium	Medium	Medium	Medium	Medium	Medium
		Shoreline development	Medium	Low	Medium	Medium	Medium	Medium
		Local diversions	Low	Medium	Low	Low	Medium	Low
		Point source sediment	Low	Low	Low	Low	Medium	Low
		Dredging and disposal of dredged material	Low	Low	Low	Low	Low	Low
		Augmentation	Low	Low	Low	Low	Low	Low
		In-water construction	Low	Low	Low	Low	Low	Low
		Sand/gravel mining	Low	Low	Low	Low	Low	Low

Listing Factor	Threat Category	Specific Threat	Sacramento River Basin					
			Eggs	**Data Sufficiency**	**Larvae/ Juveniles**	**Data Sufficiency**	**Adults**	**Data Sufficiency**
A. Habitat Destruction, Modification, or Curtailment	Barriers to Migration	Impoundments			**Low**	**Medium**	**High**	**High**
		Anthropogenic underwater sound			**Low**	**Low**	**Low**	**Low**
		Bypasses			**Low**	**Low**	**Medium**	**Medium**
		In-water structures			**Low**	**Low**	**Low**	**Medium**
		Anthropogenic light			**Low**	**Low**	**Low**	**Low**
		Local diversions			**Low**	**Medium**	**Low**	**Medium**
	Water Depth Modification	Non-point source sediment	**Medium**	**Low**	**Medium**	**Low**	**High**	**Low**
		Impoundments	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Medium**
		Mitigation and restoration	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**
		Dredging and disposal of dredged material	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		In-water construction	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		Point source sediment	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
	Loss of Wetland Function	Shoreline development	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**
		In-water construction	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
B. Overutilization for Recreational, Commercial, Scientific, or Educational Purposes	Take	Poaching	**Medium**	**Low**	**Low**	**Low**	**Medium**	**Medium**
		Fisheries			**Low**	**Low**	**Low**	**Medium**
		Derelict fishing gear	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		Scientific research activities	**Low**	**High**	**Low**	**High**	**Low**	**High**
	Reduced Genetic Diversity	Artificial propagation of green sturgeon			**Low**	**Low**	**Low**	**Low**
C. Disease and Predation	Disease	Water quality	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**
		Native and non-native species	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		Hatcheries	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
	Predation	Native species	**High**	**Medium**	**Medium**	**Medium**		
		Marine mammals			**Low**	**Low**	**Low**	**Low**
		Non-native species	**High**	**Medium**	**Medium**	**Low**		
E. Other Natural or Man-made Factors	Competition for Habitat	Native and non-native species			**High**	**Low**	**Medium**	**Low**
	Take	Electromagnetic field			**Low**	**Low**	**Low**	**Low**
		Anthropogenic underwater sound	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		Entrainment at water diversion intakes	**Low**	**Low**	**Medium**	**Medium**	**Low**	**Low**
		Vessel propeller strikes			**Low**	**Low**	**Low**	**Low**

Listing Factor	Threat Category	Specific Threat	San Francisco Bay Delta Estuary				Coastal Bays and Estuaries		Nearshore Marine	
			Juveniles	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**
A. Habitat Destruction, Modification, or Curtailment	Altered Water Flow	Channel control structures	**Very High**	**Low**	**Very High**	**Low**				
		Impoundments	**Very High**	**Low**	**High**	**Medium**	**High**	**Medium**		
		Upstream Diversions	**High**	**Low**	**Medium**	**Low**	**Medium**	**Medium**		
		Local Diversions	**Low**	**Medium**	**Low**	**Medium**				
	Altered Prey Base	Non-native species	**Medium**	**Low**	**Medium**	**Low**	**Very High**	**Low**	**Very High**	**Low**
		Global climate change	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
		Non-point source contaminants	**High**	**Medium**	**Medium**	**Low**	**Medium**	**Low**	**Low**	**Low**
		Point source contaminants	**Low**	**Medium**	**Low**	**Medium**	**Medium**	**Low**	**Low**	**Low**
		Harvest of prey species	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**
		Bottom trawling							**Medium**	**Low**
		Dredging and disposal or dredged materials	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Medium**
		Sand mining	**Low**	**Low**	**Low**	**Low**				
		In-water structures					**Low**	**Low**	**Low**	**Low**
		Electromagnetic field							**Low**	**Low**
	Altered Water Temperature	Global climate change					**Very High**	**Low**	**High**	**Low**
		Impoundments					**High**	**Medium**	**Low**	**Medium**
		Point source thermal effluent					**Low**	**Low**	**Low**	**Medium**
		Upstream diversions					**Medium**	**Medium**	**Low**	**Medium**
	Contaminants	Non-point source contaminants	**High**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Low**	**Low**
		Point source contaminants	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Low**	**Low**
		Oil and chemical spills	**Low**	**Low**	**Low**	**Low**	**High**	**Low**	**Medium**	**Medium**
		Dredging and disposal of dredged material	**Low**	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**	**Medium**
		In-water construction	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Medium**
		Aquaculture					**Low**	**Low**	**Low**	**Low**
	Altered Sediment	Impoundments					**High**	**Low**	**Medium**	**Low**
		Non-point source sediment					**Medium**	**Low**	**Low**	**Low**
		Channel control structures					**Medium**	**Low**		
		Shoreline development					**Medium**	**Low**		
		Upstream diversions					**Medium**	**Low**		
		Dredging and disposal of dredged material					**Low**	**Medium**	**Low**	**Medium**

Listing Factor	Threat Category	Specific Threat	San Francisco Bay Delta Estuary				Coastal Bays and Estuaries		Nearshore Marine	
			Juveniles	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**
A. Habitat Destruction, Modification, or Curtailment	Altered Sediment	Augmentation					**Low**	**Low**		
		In-water construction					**Low**	**Low**		
		Beach renourishment					**Low**	**Low**		
		Sand/gravel mining					**Low**	**Medium**		
	Barriers to Migration	Water quality	**Low**	**Low**	**Low**	**Low**	**High**	**Low**	**Medium**	**Low**
		Anthropogenic underwater sound	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**
		Electromagnetic field	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**
		In-water structures	**Low**	**Low**	**Low**	**Low**				
		Anthropogenic light					**Low**	**Medium**	**Low**	**Low**
	Water Depth Modification	Non-point source sediment					**Medium**	**Medium**	**Low**	**Medium**
		Impoundments					**Medium**	**Medium**		
		Mitigation and restoration					**Low**	**Medium**		
		Dredging and disposal of dredged material	**Low**	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**
		In-water construction					**Low**	**Medium**		
		Sand/gravel mining			**Low**	**Low**	**Low**	**Medium**		
	Loss of Wetland Function	Non-native species	**Medium**	**Low**	**Low**	**Low**	**High**	**Low**		
		Shoreline development	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**		
		In-water construction	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**		
		Dredging and disposal of dredged material	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**		
		Beach renourishment					**Low**	**Low**		
	Altered Turbidity	Impoundments					**High**	**Low**	**Medium**	**Low**
		Shoreline development					**Medium**	**Low**		
		Dredging and disposal of dredged material					**Low**	**Low**	**Low**	**Low**
		Non-point source turbidity					**Low**	**Low**	**Low**	**Low**
		Beach renourishment					**Low**	**Low**		
		Point source turbidity					**Low**	**Low**		
B. Overutilization for Recreational, Commercial, Scientific, or Educational Purposes	Take	Poaching	**Low**	**Low**	**Medium**	**Low**	**Low**	**Medium**	**Low**	**Low**
		Fisheries	**Low**	**Medium**	**Low**	**High**	**Medium**	**Medium**	**Medium**	**Medium**
		Derelict fishing gear					**Medium**	**Low**	**Low**	**Low**
		Scientific research activities	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**Medium**

Listing Factor	Threat Category	Specific Threat	San Francisco Bay Delta Estuary				Coastal Bays and Estuaries		Nearshore Marine	
			Juveniles	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**	**Adults/ Subadults**	**Data Sufficiency**
C. Disease and Predation	Disease	Water quality	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**High**	**Low**
		Native and non-native species	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**High**	**Low**
		Hatcheries	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**	**Low**
	Predation	Native species	**High**	**Low**	**Medium**	**Low**	**High**	**Low**	**Low**	**Low**
		Marine mammals	**Medium**	**Low**	**High**	**Low**	**High**	**Low**	**Low**	**Low**
		Non-native species	**High**	**Low**						
E. Other Natural or Man-made Factors	Competition for Habitat	Native and non-native species	**Medium**	**Low**			**High**	**Low**	**High**	**Low**
	Take	Electromagnetic field	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**High**	**Low**
		Anthropogenic underwater sound	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Medium**	**Low**
		Entrainment at water diversion intakes	**Low**	**High**	**Low**	**High**	**Low**	**Low**		
		Entrainment from hydrokinetic projects	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**
		Vessel propeller strikes	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		Entrainment from dredging	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**	**Low**
		Water quality	**Low**	**Low**	**Low**	**Low**				

Altered Prey Base

Within this category, non-native species, climate change, and contaminants are all specific threats ranked as highly impacting the sDPS prey base. Data sufficiency for almost all of the areas and life stages identified was considered low.

In the SRB, an altered prey base was considered a High threat to larval/juvenile sDPS due to non-native species and global climate change. The establishment of non-native species of plants and invertebrates (e.g., mussels, clams) has the potential to alter food resources for the sDPS and the effects could be exacerbated by climate change. Projected 33% salinity increases in the SRB in the 21st century due to climate change may result in declining habitat quality and food web productivity (CH2M HILL 2014).

In the SFBDE, an altered prey base due to global climate change was considered a High threat to juvenile and adult life stages, while the impact of non-point source contaminants through run-off and agricultural practices on the prey base were considered a High threat to juveniles (see Contaminants section below). Laboratory experiments confirm the potential negative impacts on green sturgeon of predicted salinity and prey base changes due to climate change in the San Francisco Bay Delta (Sardella and Kultz 2014; Haller et al. 2015; Vaz et al. 2015). Research conducted on white and green sturgeon has shown that many of the non-native food resources including the non-native overbite clam, *Corbula amurensis*, are either non-digestible (for white sturgeon; Kogut 2008) or, if digested, may expose green sturgeon to selenium (CDFG 2002; Linville et al. 2002). Bioaccumulation and exposure to selenium, as well as other contaminants, may have negative effects on green sturgeon and has been shown to cause viability and reproductive issues in other species (see Contaminants section below).

Within the CBE and the NM, an altered prey base due to non-native species and climate change was recognized as a Very High and High threat, respectively. Data sufficiency was considered low. As mentioned above, the sDPS utilizes CBE along the west coast for feeding. Some of these estuaries, such as Willapa Bay, have been impacted by non-native and invasive species including *Spartina alterniflora* and *Zostera japonica*, which can alter prey resources for the sDPS (Grosholz et al. 2009; Patten 2014; Moser et al. 2017). An invasive isopod affecting blue mud shrimp (*U. pugettensis*) in estuaries (Chapman et al. 2012) and the invasive European green crab, *Carcinus maenas*, that preys on burrowing shrimp and displaces habitat, could also impact sDPS prey resources (Jamieson 1998; NMFS 2014). In the Umpqua River estuary, non-native warmwater species like smallmouth bass could potentially impact food availability, particularly in the upper estuary (ODFW 2017). In both the CBE and NM, global climate change may have an adverse effect on benthic prey either directly or indirectly. Climatic shifts/ocean acidification could also impact invasive species abundance. The Recovery Team confirmed that studies are needed to understand the impacts of non-native species and climate change on the sDPS prey base in the CBE and NM environments. In the NM, particularly, little is known about the prey base of the sDPS. Contaminants could also impact the prey base in the CBE (ranked Medium), as discussed in the Contaminants section.

Altered Water Temperature

The threat posed by altered water temperatures due to impoundments was ranked High in the SRB for eggs and juveniles, with medium data sufficiency. Impoundments alter flow regimes, which in turn affect the water temperature of the river downstream of the impoundment. If water released from the impoundments results in water temperatures that are not within the optimal thermal window for development, survival and growth will be limited.

In the Feather River, spawning has only been documented at the Thermalito Afterbay Outlet and Fish Barrier Dam (Figure 3). Late spring and summer water temperature in the lower Feather River can exceed suitable ranges for normal egg and larval development (NMFS 2016). Green sturgeon spawned in 2011 and 2017 in the Feather River at the Thermalito Afterbay Outlet and Fish Barrier Dam, respectively. Water temperature was substantially cooler than average in both years, likely due to the above average flow that occurred in spring.

Sacramento River temperature management was rated as a Medium threat to all life stages by the Recovery Team. The California State Water Resource Control Board Water Rights Orders 90-05 and 91-01 and the Reasonable and Prudent Alternative (RPA) issued for the long-term operations of the Central Valley Project and State Water Project (NMFS 2009a) requires maintenance of 13.3°C water temperature at a compliance point ranging from RBDD to above the confluence of the Sacramento River and Clear Creek. Anderson et al. (2009) felt temperatures associated with this compliance point might reduce the growth rate of larvae and post-larvae relative to warmer temperatures. Under laboratory conditions, Mayfield and Cech (2004) reported optimal bio-energetic performance of age-0 and age-1 nDPS green sturgeon at 15 to 19°C. Summer water temperatures in the upper Sacramento River have typically been below this range, within lab-based optima for nDPS egg development but below lab-based optima for nDPS larval and juvenile growth (Van Eenennaam et al. 2005; Mayfield and Cech 2004; Allen et al. 2006). Notably, temperatures throughout the upper Sacramento River were in excess of 13.3°C during periods of 2014 and 2015 due to historic drought but the effect of this on green sturgeon production remains unclear. Although the first successful season of directed juvenile green sturgeon sampling near RBDD occurred during elevated temperatures in 2015, juveniles were subsequently collected in 2016 and 2017 sampling efforts (USFWS unpublished data). Furthermore, high larval green sturgeon catch at RBDD has occurred in years with relatively low water temperatures (1995, 2011, 2016, and 2017; USFWS unpublished data). The effect of cold-water releases from Keswick Dam may have a greater impact on sDPS spawning and incubation in the uppermost accessible reach of the Sacramento River below ACID Dam. ACID Dam currently serves as a migration barrier, but low water temperature could deter sDPS spawning even if passage was restored to this reach.

Temperatures in the Yuba River should be evaluated as other sDPS restoration efforts described within this plan are undertaken. A 2010 report suggested that late summer and early fall water temperatures were too warm to support green sturgeon reproduction (Lower Yuba River Accord River Management Team Planning Group 2010). More recent analysis suggests that temperatures fall within optimal ranges (YCWA 2017). If upstream sturgeon passage is restored within the Yuba River, temperature suitability should be reevaluated using information on optimal temperature windows potentially made available through future monitoring in the Sacramento and Feather rivers.

The threat posed by altered water temperatures due to impoundments was ranked High in the CBE, with medium data sufficiency. Impoundment outflow temperature can be one of multiple factors influencing water temperatures in the CBE. The Recovery Team indicated that the threat was high because of the potential effect of altered water temperatures on food resources and sDPS green sturgeon growth in the CBE. Additional studies are needed to understand the relationship between water temperature and foraging habitat in the CBE.

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

In the CBE, similar climate-change induced habitat quality impacts in estuaries in Washington and Oregon could affect the health of sub-adult and adult sDPS. Sea level rise is predicted to cause losses of tidal habitats in Willapa Bay and Grays Harbor (Washington State Department of Ecology 2012). Green sturgeon occupy the CBE in summer months such that elevated water temperatures and associated changes in water quality in CBEs may affect behavior (e.g., occupancy length), bioenergetic performance, and growth (Moser and Lindley 2007; Washington State Department of Ecology 2012; Borin 2017). In the Umpqua estuary, increased temperatures have occurred due to factors including below average snow packs, early cessation of rains, and early and prolonged above average air temperatures. Subadult and adult sDPS can, however, occupy habitats with a wide range of temperature, salinity, and DO levels (Kelly et al. 2007; Moser and Lindley 2007), so predicting the impact of climate change in these environments is difficult. In the NM and CBE, changing ocean conditions such as rising temperatures, ocean acidification, and changes of migrations of prey species could impact the sDPS. Overall, our knowledge of the environmental impact of climate change is increasing, but the direction of the impact on the sDPS is unknown at this point in time. Monitoring potential impacts into the future is important.

Contaminants

Non-point and point source contaminants were seen as a High threat to all life stages within the SRB, with low to medium data sufficiency. Exposure to contaminants within the SRB stems from agriculture runoff, urban development, discharge from various industries and user groups, and legacy contaminants from mining. Land use practices continue to cause deposition of mercury, polychlorinated biphenyls (PCB), heavy metals, and persistent organochlorine pesticides in watersheds throughout the Central Valley. Although most of these contaminants are at low concentrations in the food chain, they continue to work their way into the base of the food web, particularly when sediments are disturbed and compounds are released into the water column. Contaminants found in the SRB were determined to pose the greatest threat to eggs, larvae, and juveniles, resulting in reduced growth, injury, or mortality. Contaminants could also negatively affect the reproductive capacity of female adults during spawning. In addition, pyrethroid insecticides used in crop protection and home pest control may affect aquatic invertebrates and the prey base of the sDPS. A recent Biological Opinion found that the pesticides chlorpyrifos, diazinon, and malathion jeopardize green sturgeon and adversely modify their critical habitat (NMFS 2017). These pesticides were found to potentially cause direct mortality, impaired behavior, and a reduced prey base and could impact green sturgeon in SRB, SFBDE, and CBE environments (NMFS 2017).

Non-point source contaminants entering the SFBDE as runoff (from sources such as urban sites, forests, agricultural lands, landfills, pastures, mines, nurseries, etc.) were considered a High threat to juvenile green sturgeon, with low to medium data sufficiency. Poor agricultural practices result in low water-holding retention of the soil causing high runoff rates of pesticides, petroleum hydrocarbons, and other contaminants during rain events and irrigation. Due to their widespread nature, increased permanence within the environment, and the fact that effects are difficult to reverse, non-point source contaminants were considered to potentially have a negative impact on juvenile growth and reproductive capacity of females. Although the accumulation of contaminants in green sturgeon has not been studied, bioaccumulation of contaminants in white sturgeon is well documented (e.g., Feist et al. 2005) and may also occur in green sturgeon. As stated above, the diet of green sturgeon in the estuary includes overbite clams, a non-native species known to bioaccumulate selenium (CDFG 2002; Linville et al. 2002). Laboratory research has revealed that green sturgeon are highly sensitive to selenium with potential impacts including reduced growth and organ abnormalities (Silvestre et al. 2010, Bakke et al. 2010; Lee et al. 2011; De Riu et al. 2014).

Point and non-point source contaminants were also ranked as a Medium threat to the sDPS and their prey base within the CBE. The application of chemicals and pesticides (e.g., carbaryl, imidacloprid) to control burrowing shrimp (i.e., ghost shrimp (*Neotrypaea californiensis*) and mud shrimp (*Upogebia pugettensis*)) populations in Washington estuaries may also pose a threat to the sDPS, through porewater exposure or by feeding on affected burrowing shrimp (Dumbauld et al. 2008; NMFS 2009b; Frew 2013; Frew et al. 2015). Carbaryl application has been phased out and the chemical imidacloprid, an alternative to carbaryl, is being considered for use in Washington. A recent field experimentation and modeling study of the impact of imidacloprid exposure on green sturgeon found no evidence of acute toxicity and minimal risk to the species (Frew 2013; Frew et al. 2015). Various industries release contaminants into bays and estuaries utilized by sDPS in the CBE (e.g., Yaquina Bay, Coos Bay, Winchester Bay). Information collected by WDFW indicates the presence of several contaminants in the blood plasma of green sturgeon sampled in Washington (e.g., DDT, DDD, DDE, BHC, Heptachlor, Aldrin; Langness 2007). Research is needed to understand the effects of contaminant exposure on green sturgeon and their prey species.

The threat of oil and chemical spills was recognized as a High threat in the CBE with medium data sufficiency, but consensus was not reached on specific impacts to the sDPS and the permanence of the threat. Updating existing oil and chemical response plans so as to minimize sDPS impacts was seen as useful in mitigating this threat.

Altered Sediments

The threat of altered sediments due to impoundments was ranked High in the CBE. The creation of upstream dams and impoundments can reduce sediment delivery to bays and estuaries. This can impact sDPS feeding habitat quality and quantity through changes in sediment deposition and composition and subsequent changes in prey resources or through changes in turbidity that could impact habitat use and predation by sight-predators. In the Columbia River basin, impoundments have reduced total sediment discharge to about one-third of nineteenth-century levels. Data sufficiency was low and the effects on green sturgeon are largely theoretical and have not been studied. Additional research in this area was considered a priority.

Barriers to Migration

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

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

Farther downstream, the Yolo and Sutter bypasses can also serve as a barrier to sDPS migration during high water events (Thomas et al. 2013). During some high flow events, adult green sturgeon enter the Yolo and Sutter bypasses and become stranded when the water recedes. In some cases, adult sturgeon remain stranded in small isolated bypass ponds through the summer or fall, making them extremely vulnerable to poaching and other sources of mortality. In 2011, 24 sDPS were rescued from the Yolo and Sutter bypasses (Thomas et al. 2013). Since relocation efforts cannot prevent all mortality associated with stranding, and the loss of even a few adult fish periodically should be avoided, it is important to construct structures at these weirs that allow volitional passage of upstream migrating green sturgeon.

The Sacramento Deep Water Ship Channel can also block migration. There are multiple upriver migration routes through the lower Sacramento River that either lead to the middle Sacramento River and Feather River or terminate in areas with no upriver passage (e.g., Fremont Weir). The Sacramento Deep Water Ship Channel terminates at closed locks in the City of West Sacramento that separates the ship channel from the Sacramento River. These locks are approximately 32 kilometers upstream from open migration routes to spawning habitat and it is uncertain how long fish encountering the closed locks search for open routes and resume normal migration. Adult Chinook salmon are frequently observed in the vicinity of these locks during the fall migration period attempting to enter the Sacramento River. Acoustically tagged adult sDPS have not been detected in the vicinity of the Sacramento Deep Water Ship Channel locks. In 2011, 24 sDPS without acoustic tags were collected at Fremont and Tisdale weirs during relocation and tagging efforts (Thomas et al. 2013). Hence, the number of acoustically tagged fish and associated detection has been insufficient to identify all migratory behaviors and potential barriers.

Within the Delta, the Delta Cross Channel may negatively impact migration. The Cross Channel is a controlled diversion channel that tagged sDPS are known to use en route to and from upstream spawning sites (Israel et al. 2010). Operation of the Delta Cross Channel gates may influence downstream migration by providing false migration cues for juvenile and adult sturgeon to move from lower Sacramento River to the central Delta rather than their intended destination of the western Delta and San Francisco Bay.

In the Feather River, the boulder weir at Sunset Pumps is the first potential barrier encountered by migrating adult sDPS (Figure 3). The weir creates a partial barrier to adult sDPS migration to the only confirmed spawning location in the Feather River (Seesholtz et al. 2015). This barrier is flow dependent. With construction of Oroville Dam, late-winter and spring peak flows were reduced thus hindering upstream migration. Niggemyer and Duster (2003) described the potential flows needed for passage of green sturgeon, concluding that flows need to be higher than 10,000 cubic feet per second (cfs). During recent high flow years, such as in 2006 (44,000 cfs) and 2011 (39,000 cfs), many green sturgeon were observed upstream, although specific flows during upstream passage is unknown. Recent analysis suggests that a small number of sturgeon can pass upstream of the boulder weir when flows are very low (e.g., less than 1,500 cfs). Although it appears that some fish can pass the dam at low flows, higher flows appear necessary for successful spawning and allow larger numbers of adult sDPS to access upstream spawning sites on a consistent, annual basis. Furthermore, it is likely that historical sDPS spawning habitat above Oroville Dam (Mora et al. 2009) was dissimilar to currently accessible spawning habitat in the Feather River.

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

Within the CBE, water quality was ranked as a High threat as a barrier to migration. Data sufficiency was considered low. The degree to which this is a threat in specific estuaries and its impact on the sDPS is currently uncertain.

Water Depth Modification

Water depth modification caused by non-point source sediment was ranked as a High threat to adults within the SRB and a Medium threat to other life stages in the SRB. Impoundments and mitigation and restoration efforts (ranked Medium) were also considered as contributing to the water depth modification threat to all life stages in the SRB. Data sufficiency was considered low. Non-point source sediment includes runoff from urban areas, agriculture, forests, irrigated lands, landfills, livestock, mining operations, nurseries, orchards, etc. Removal of riparian vegetation results in increased erosion and input of fine grain material into the water. Sediment from these sources can be deposited in pools. The sDPS requires deep pools for spawning and holding in the SRB. Large impoundments (e.g., Oroville, Shasta) that reduce the frequency of high flow events may limit pool scouring and result in a reduction of pool depth. Survival and development of early life stages within the SRB may also be impacted by non-point source sediments through altered turbidity and substrate composition. At the time that the Recovery Team conducted its assessment, the High ranking for adults was attributed, in part, to the impact of water depth modification on the quantity and habitat quality of deep pools. The work of Mora (2016) indicates 50-125 areas with greater than 5m depth available on the mainstem Sacramento River depending upon the year. It is uncertain as to whether all of these pools supply sufficient habitat for spawning and holding in terms of depth and substrate. Research on the effects of sedimentation and impoundments on the sDPS within each potential spawning river system (i.e., Sacramento, Feather, Yuba) is needed. Water depth modification due to non-point sediment was ranked as a Medium threat in the CBE. Human disturbance in the Umpqua River may be causing increased sediment to reach the estuary. Monitoring will be needed moving forward as will a better understanding of the fine scale spatial use of the sDPS in the Umpqua estuary.

Loss of Wetland Function

Loss of wetland function due to non-native species was considered a High threat to adults and sub-adults in the CBE. Data sufficiency was considered low. Some of these estuaries used by the sDPS for feeding, such as Willapa Bay, have been impacted by non-native species including *Spartina alterniflora* and *Zostera japonica* as well as non-native oysters, which can alter wetland function and prey resources for the sDPS (Grosholz et al. 2009; Patten et al. 2012; Moser et al. 2017). In the SFBDE, the invasive aquatic plant *Egeria densa* is also having a negative impact on water quality and associated plant and animal species composition (Durand et al. 2016). Additional research is needed to understand the degree to which this is a threat in specific estuaries and its impact on the sDPS.

Altered Turbidity

Altered turbidity due to impoundments was ranked High for the CBE, with low data sufficiency. Impoundments upstream of bays and estuaries may result in a long-term reduction in turbidity by holding back sediment and this could conceivably increase interactions between sDPS and large predators such as marine mammals and sharks. Additional research is needed to understand the degree to which this is a threat in specific estuaries and its impacts on the sDPS.

Listing Factor B - Overutilization for Recreational, Commercial, Scientific, or Educational Purposes

No threats within this Listing Factor category were listed as High or Very High, with fisheries and poaching considered Medium in some areas. In the past, fisheries had a considerable impact on the sDPS. At present, no fishery permits directed take or retention of green sturgeon, regardless of the DPS origin, with the exception of the Yurok Tribe fishery for nDPS green sturgeon in the Klamath River (see NMFS 2015 for more detail). Incidental take of green sturgeon does occur and action and research priorities are included in the recovery plan to better quantify and manage take. Poaching of the sDPS has been documented to occur, particularly in the SRB and SFBDE and Yolo and Sutter bypasses. Understanding annual rates of poaching is a research priority.

Listing Factor C - Disease and Predation

Disease

The Recovery Team ranked disease as a High threat in the NM for adults and subadults due to water quality and native and non-native species. The recovery team recognized that there are no current reports indicating that disease poses a problem but ranked the permanence of the threat as Very High should disease transmission occur. Potential sources include disease transmittal from native and non-native species, release of diseased fish from hatcheries, and reduced immunity from exposure to poor water quality, such as dead zones. At this time, the extent of this potential threat is unknown, data sufficiency is considered low, and evaluating diseases to determine their significance to green sturgeon is a research priority in this recovery plan. Should disease be detected in the sDPS in the future, efforts to reduce exposure should be undertaken.

Predation

Predation was ranked High for eggs and Medium for larvae in the SRB and High in the SFBDE for larvae and juveniles due to native species (e.g., Sacramento sucker, pikeminnow, prickly sculpin) and non-native species (e.g., striped bass, carp, American shad, crayfish, centrarchids, catfish, non-native minnows), with low to medium data sufficiency. Additional research is needed to understand the degree to which this is a threat in specific parts of the species range, the impact of predation on the status of the sDPS, and the interaction between predation, flow, turbidity, and temperature (e.g., whether predation increases with low flow, high temperature and/or low turbidity).

Predation was also ranked High for adults and subadults in the SFBDE and CBE due to marine mammals and native fish species (CBE). Steller sea lions (*Eumetopias jubatus*) have been observed feeding on white sturgeon in the Columbia River and SFBDE region and are known to feed on green sturgeon in the Rogue River (NMFS 2015; CDFW, unpublished). Predation on the sDPS by California sea lions (*Zalophus californianus*) occurs in the Sacramento River, bays, and

Delta (CDFW 2013). Steller and California sea lion abundance has increased in recent decades (Carretta et al. 2017; Muto et al. 2017), but the impact on the sDPS has not been studied. Predation impacts on green sturgeon could intensify with the recovery of marine mammal populations as they have for salmonids (Keefer et al. 2012). Sharks also prey upon sturgeon within CBE environments (Huff et al. 2011).

Listing Factor D - The Inadequacy of Existing Regulatory Mechanisms

At the time of listing, NMFS concluded that the inadequacy of existing regulatory mechanisms had contributed significantly to the decline of sDPS green sturgeon and to the severity of threats that the species faced in terms of fisheries, blocked passage, and water diversions (71 FR 17757, April 7, 2006). Some of these issues have been addressed as described in NMFS (2015), but improvements to regulatory mechanisms could still be made. Regulatory mechanisms were considered by the Recovery Team when ranking the threats under listing factors A through C and E. High or Very High rankings for many threats indicates that underlying regulatory mechanisms are likely inadequate. This broader regulatory landscape has been recognized when defining recovery partners. There is a need to establish or improve regulatory mechanisms associated with Listing Factors A through C and E and, as highlighted throughout this recovery plan, specifically the regulatory mechanisms (e.g., Clean Water Act Section 404, ESA Section 7, California Fish and Game Code Section 1602, Federal Energy and Regulatory Commission licensing, state Fishery Management and Evaluation Plans) in the following areas:

- Sturgeon passage improvement at outstanding barriers to migration (e.g., boulder weir at Sunset Pumps, Daguerre Point Dam);
- Modification of impoundment operations or facilities to address flow, water temperature, and sediment impacts (e.g., Oroville-Thermalito Complex, Keswick Reservoir, Shasta Lake);
- Improvement of lock and gate operations at the Port of Sacramento and Delta Cross Channel;
- Enforcement of poaching and other fishery regulations (e.g., bycatch in state fisheries);
- Screening criteria and/or operations guidelines for agricultural, municipal, and industrial water diversions in the SRB and SFBDE;
- Land use regulations for non-point and point source contaminants in the SRB and SFBDE;
- Control of invasive species (e.g., overbite clam) in the SFBDE and CBE;
- Response plans for oil and chemical spills in the SFBDE and CBE; and
- Permitting of offshore and near-shore kinetic energy projects in the CBE and NM habitat.

Listing Factor E - Other Factors

Competition for habitat by native and non-native species was a threat ranked as High in the SRB (larvae/juveniles) and in the CBE and NM (subadults/adults). Data sufficiency for these threats was considered low. With habitat alteration in the SRB, ranges of native species (e.g., Sacramento suckers, salmonids, white sturgeon) may have greater overlap with the sDPS, making competition more of a threat. Non-native species (e.g., striped bass) also compete for resources. Within the CBE, competition between white and green sturgeon could occur as habitats contract, especially given the impact of non-native species as described above in terms of wetland function and prey base. Within the NM, the Recovery Team recognized the need for more research looking at specific habitat utilization in these environments. Overall, additional research is needed to better evaluate this theat.

Electromagnetic fields were also considered a High threat in the NM, with low data sufficiency. Development and operation of offshore and near shore kinetic energy projects within the range of the sDPS (reviewed in NMFS 2015) could cause direct mortality, habitat loss, or migration, feeding or habitat impacts due to electromagnetic fields (Nelson et al. 2008; Normandeau et al. 2011; EPRI 2013). A similar 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 to San Francisco 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 through the area. Additional research is needed regarding this threat, including that which examines the response of green sturgeon to different levels of electromagnetic fields (EPRI 2013). It should be noted that the permitting process for these facilities considers potential sDPS effects and monitoring may be a requirement for any facility receiving a permit.

Although ranked as a Medium threat in the SRB and Low in all other areas, entrainment/impingement of green sturgeon larvae at screened and unscreened agricultural, municipal, and industrial water diversions in the SRB and SFBDE has recently been identified as an important threat. Green sturgeon appear to be highly vulnerable to entrainment in the thousands of diversions that exist in the Sacramento River and Delta (Mussen et al. 2014). Current screen criteria may not be useful in preventing sDPS impingement and entrainment (see NMFS 2015). In the laboratory, green sturgeon contact screens and become impinged upon them more frequently than white sturgeon (Poletto et al. 2014a). Flow and pipe configuration affects entrainment rates (Mussen et al. 2014; Poletto et al. 2014b) and may be strategies for addressing this threat. A threat-based recovery criterion has been included in the plan to address this threat.

Conservation Efforts

As described previously, the sDPS has benefited from the prohibition of green sturgeon retention in commercial and recreational fisheries in the US and Canada, the decommissioning of RBDD, the conservation measures provided through the ESA 4(d) rule, and the critical habitat designation. The States of California, Oregon, and Washington have adopted measures to increase monitoring of green sturgeon incidental capture. California has established specific rules to protect the sDPS population, prohibiting fishing for green or white sturgeon year-round in the mainstem Sacramento River from Highway 162 (rkm 283) to Keswick Dam (rkm 485) and Yolo Bypass, prohibiting the removal of incidentally hooked green sturgeon from the water, only allowing the use of barbless hooks, prohibiting use of wire leaders and snares, and increasing fines for poaching. The CDFW also relocates sDPS stranded in the Yolo and Sutter bypasses and provides enforcement regarding poaching and fisheries infractions.

Since the early 1990s, a number of restoration projects have been completed in California's Central Valley with likely benefits to sDPS (e.g., barrier modifications for fish passage, habitat restoration in wetland areas, fish screens; see CALFED 2000; CALFED 2005). In cases such as complete barrier removal (e.g., RBDD) there are obvious benefits to green sturgeon. Screening criteria for green sturgeon have not been developed, and the benefits to sturgeon of projects intended to reduce salmonid impingement and entrainment at diversions are not fully understood. However, implementation of fish screens most likely reduces some negative effects of unscreened diversions (e.g., entrainment) to green sturgeon. The Central Valley Project and Central Valley Project Improvement Act (CVPIA) have initiated habitat restoration, water acquisitions for the environment, and fish screening projects. These projects also have some ancillary benefits to sturgeon but are mostly intended to increase anadromous salmonid abundance. The revision of CVPIA priorities could include consideration of the projects described in this recovery plan.

As noted above, juvenile sturgeon can become entrained in water diversions in the SRB and SFBDE. Efforts to salvage green sturgeon at the Tracy Fish Collection Facility and the Skinner Delta Fish Protective Facility in the South Delta have been conducted for decades. The numbers of green sturgeon observed in these facilities is typically low (i.e., a few individuals per year).

Known Biological Constraints and Needs

As detailed in the sections above, the sDPS has inherent vulnerability due to its slow growth, late maturity, and infrequent spawning; thus, population growth is inherently limited. The sDPS relies upon multiple habitats along the entire west coast of North America for the completion of its life history and needs accessibility, connectivity, and adequate habitat quality in all areas. Vulnerability is enhanced by the fact that there is only one population in the SRB that has been documented to spawn annually (i.e., in the mainstem Sacramento; annual spawning has not been documented in the Feather or Yuba River). The SRB is also a stressed environment with competing demands on water resources for people and wildlife. Given that flow, temperature, and habitat access are parameters influential to the sDPS life-history, these characteristics are important to consider within the recovery plan.

Chapter II. Recovery Goal, Objective, and Criteria

Recovery Goal

Recovery is the process by which listed species and their ecosystems are restored and their future safeguarded to the point that protections under the ESA are no longer needed. Thus, the goal of this recovery plan is to recover sDPS green sturgeon and consequently remove it from the Federal List of Endangered and Threatened Wildlife (50 CFR 17.11).

Recovery Objective

To achieve the goal of recovery, the objective of this recovery plan is to increase sDPS green sturgeon abundance, distribution, productivity, and diversity by reducing threats associated with habitat degradation and access, contaminants, and take.

Recovery Criteria

The following recovery criteria are provided in order to determine when the recovery objectives have been met. Recovery criteria are targets or values by which progress toward achievement of recovery objectives can be measured, and may include population demographics, management or elimination of threats by specific mechanisms, and specific habitat conditions. Delisting may be considered when the recovery criteria are met, although it is possible that delisting could occur without meeting all of the recovery criteria if the best available information indicates that the species no longer meets the definition of endangered or threatened. In the case of the sDPS, it is possible that because of the interaction between the threats and the species' population responses, fully achieving all of the recovery criteria may not be necessary to achieve the recovery objective. Changes to the species' status and delisting would be made through additional rulemaking after considering the same five ESA factors considered in listing decisions and taking new information into account.

The criteria are organized below 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

The following demographic recovery criteria describe a population at low risk of extinction over the foreseeable future. Because we do not have much demographic information for sDPS green sturgeon, we developed these criteria using general principles of conservation biology. We also reviewed recovery plans for other species and focused on four factors considered important for assessing the viability of populations: abundance, distribution, productivity, and diversity. To develop the criteria for adult population abundance, we used the best available information from scientific literature relating population viability to abundance. To develop criteria for distribution, productivity, and diversity, we considered the threats faced by green sturgeon and the best available information on population viability and green sturgeon population dynamics.

Our goal is to reduce the risk of extinction to an acceptably low level such that the species is no longer considered endangered or threatened; however, at this time we do not have the biological basis to define that level quantitatively. Explicitly defining the acceptable level of extinction risk (e.g., less than 5% risk of extinction in 100 years) can be useful as the basis for developing demographic recovery criteria (e.g., identifying the adult population size and spawning population size needed to reduce extinction risk to the acceptable level) and evaluating progress toward recovery. However, to estimate extinction risk, we need demographic information to develop population viability models. We currently have little of the information needed to model and estimate extinction risk for sDPS green sturgeon. This limits our ability to define an acceptable risk level and the value of defining this risk level. We note that recovery plans for other sturgeons also do not explicitly define what constitutes a "low" extinction risk. The following demographic criteria are interim and may be updated as viability models or other pertinent information becomes available.

Abundance

Demographic Recovery Criterion 1. The adult sDPS 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 be comprised of a combined total, from all spawning locations, of at least 500 adult fish in any given year.

A viable population is sufficiently abundant when: 1) it has a high probability of surviving environmental variation of the patterns and magnitudes observed in the past and expected in the future; 2) compensatory processes provide resilience to environmental and anthropogenic perturbation; 3) its genetic diversity is maintained over the long term; and 4) it provides important ecological functions throughout its life-cycle (McElhany et al. 2000). Additionally, a population is considered critically low in abundance if: 1) depensatory processes are likely to reduce it below replacement; 2) it is at risk from inbreeding depression or fixation of deleterious mutations; and 3) productivity varies due to demographic stochasticity and becomes a substantial source of risk (*ibid*.).

As we do not have reliable estimates of historical or current sDPS green sturgeon abundance, we did not use green sturgeon population data to develop these criteria. Instead, we developed the adult abundance criteria using the best available information from general principles in conservation biology relating population viability to abundance. Long-term abundance objectives for conservation are generally based on minimum population sizes that are naturally self-sustaining. A wide range of viable abundance values has been established for different species. Census numbers are typically several times greater than effective population size because of non-random mating. Population abundance targets ranging from 1,000 to 20,000 have been recommended for various species (IUCN 2001; Fisheries and Oceans Canada 2014). Other sturgeon recovery plans have identified abundance objectives ranging from 1,000 per population with multiple populations (Fisheries and Oceans Canada 2014) to a single population value from 2,000 to 5,000 adults (IUCN 2001; Hildebrand and Parsley 2013).

In theory, an effective population size of 500 or more adults is needed for a population to be naturally self-sustaining, based on the principle that loss of genetic diversity through drift is significant when effective population sizes are less than 500 (Franklin 1980; Soulé 1980). To estimate the needed census population size to achieve an effective population size of 500, we need to know the ratio of the census to effective population size. This ratio is not known for green sturgeon or other sturgeon species. Hence, a ratio of adult census to effective population size that is widely used in anadromous fish recovery planning (about 0.2; Waples et al. 2004) was also employed in this plan. Using this ratio, we estimate that the minimum census population size of 2,500 adult sDPS green sturgeon is needed for a naturally self-sustaining population at low risk of extinction. Because abundance estimates contain observational error, population targets may need to be much larger than the desired population size in order to be confident that the guideline is actually met (McElhany et al. 2000). For example, Mora (2016) estimated an average run size of adult sDPS in the Sacramento River at 571 individuals, with a 95% confidence limit of 529 to 613 individuals. The total number of adults in the sDPS was estimated to be 2,106 individuals, with 95% confidence limits of 1,246 to 2,966 individuals. Therefore, we have added a buffer of 20%, which increases the census population to 3,000 adults. The Recovery Team agreed that it is biologically feasible for sDPS green sturgeon to achieve an effective population size of greater than 500 adults and a census population size of greater than 3,000 adults. These abundance criteria should be updated if relevant information on green sturgeon population dynamics becomes available. For example, we assume roughly equivalent run-size and annual effective population estimates in calculating minimum abundance criteria. This assumption relies on a 1:1 sex ratio based on data from nDPS spawners (Erickson and Webb 2007; Webb and Erickson 2007). Criteria should be updated accordingly if future information indicates differences in the annual effective population size and the spawner or run-size estimate. Furthermore, if the adult sDPS green sturgeon census population exceeds 3,000 upon issuance of this recovery plan, then the census population must remain stable or increase.

Because not all adults return to spawn each year, methods will be needed to estimate the census population size. One method is to calculate a running geometric average of the annual spawning run size over a 6-year period (the maximum spawning periodicity). A running average would account for variation in spawning periodicity and natural inter-annual fluctuations in run size. Based on our current understanding of spawning periodicity (range of 2-6 years, mean 3.69), the average annual spawning run would need to be 813 adults (combined from all spawning locations), which would represent a census population of 3,000. The average should be calculated with geometric mean and not arithmetic mean to reduce the influence of extreme values (e.g., one good year or one bad year). A minimum total annual spawning run for all locations of at least 500 adults is needed to ensure resiliency. Finally, due to late maturation and low natural mortality of adult sturgeon, an adult population may remain stable over a relatively long time period (e.g., 20 years) even when little to no juvenile recruitment occurs. Thus, adult demographic criteria should be maintained for at least three generations (approximately 66 years) to ensure recruitment to the spawning population is consistently occurring at a level that offsets adult mortality. This criterion and timeframe should consider monitoring conducted to date (Mora et al. 2018) and be updated in the future based on new information regarding spawning periodicity and sex ratio. It should also be updated as our ability to detect effective population size using genetic techniques is refined.

Distribution

Demographic Recovery Criterion 2. sDPS 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.

Another feature of a population at low risk of extinction is having a spatial structure or distribution such that stochastic events do not significantly threaten the population's long-term viability. Loss of access to historical spawning habitat and habitat degradation have largely restricted the sDPS to one reach of the mainstem Sacramento River and made the population vulnerable to stochastic events. The listing highlighted this as a major threat to the species. To reduce this risk, consistent spawning is needed in at least one additional location outside the mainstem Sacramento River.

Successful annual spawning outside of the mainstem Sacramento River should be promoted in the Feather and Yuba rivers, because green sturgeon are already found in these rivers. The Yuba River is a tributary to the Feather River. If successful sDPS green sturgeon spawning in these rivers cannot be achieved, then rivers that are either currently unoccupied or not known to support spawning populations (e.g., San Joaquin, Stanislaus, Tuolumne, Russian, American rivers) should be investigated to determine whether habitat in those rivers could support successful spawning of adults and rearing of larvae. Restoration of habitat and access to upstream reaches may be needed to establish consistent spawning in the Feather and Yuba rivers. The presence of larvae in these rivers can be used to confirm successful spawning. Larval sampling may also be used to estimate the annual spawner abundance (i.e., annual spawning run size) using genetic techniques; however, we would need to collect enough larvae to sufficiently represent the spawning adults in that year. At this time, estimates of annual spawner abundance are likely to require observations of adult green sturgeon in putative spawning habitat or genetic applications (see Criterion 1).

Productivity

Demographic Recovery Criterion 3. A net positive trend in juvenile and subadult abundance is observed over the course of at least 20 years.

Productivity refers to a population's growth rate. For a threatened population like sDPS green sturgeon, recovery involves achieving positive growth rates. Increasing trends in juvenile and subadult numbers are important indicators of a recovering population.

Long-term recruitment is a function of the number of annual spawners or population fecundity, the quality of spawning habitat, and the magnitude of annual early life stage survival. Because the adult abundance objectives can be achieved in a number of ways and because recruitment is difficult to measure, we did not identify a specific annual recruitment objective for sDPS green sturgeon. Instead, the trend in juvenile and subadult abundance is used to measure population growth. A net positive trend in juvenile and subadult abundance (e.g., based on time series analysis) would indicate successful recruitment and survival of early life stages. This, in combination with achievement of the adult abundance criterion, would indicate sufficient recruitment. Data for this criterion will be based on a time series analysis over at least 20 years and include 20 annual data points that indicate increasing or stable juvenile and subadult abundance.

Demographic Recovery Criterion 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).

For long-lived species such as sturgeon, abundance, age structure, and sex ratios are particularly powerful indicators of long-term productivity patterns. Viable sturgeon populations are characterized by a broad distribution of size classes and ages. Long term stability in size and age distributions, or population at equilibrium, can signify a healthy population with normal levels of life stage mortality and recruitment. Thus, measures of population equilibrium can be used to evaluate the sDPS green sturgeon's progress toward recovery. 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 sDPS 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 sDPS in the early stages of potential recovery.

Diversity

Demographic Recovery Criterion 5. There is no net loss of sDPS green sturgeon diversity from current levels.

Diversity refers to individual and population variability in genetic, life history, behavioral, and physiological traits. Diversity is related to population viability because it allows a species to exploit a wider array of environments, protects against short-term spatial and temporal changes in the environment, and provides the raw material for surviving long-term environmental changes (McElhany et al. 2000). Thus, maintaining these types of diversity is critical to retaining the species' ability to adapt to a diverse and variable environment. At this time, we do not have methods to directly measure diversity or compare present and historical levels. However, if we use the loss of spawning habitat as a proxy, then some loss has likely occurred. Because diversity is closely tied with abundance, distribution, and productivity, this criterion may be met by improving and/or increasing spawning and rearing habitat to a level which increases spawning and/or rearing distribution or success.

Threat-Based Recovery Criteria

The following threat-based recovery criteria were developed to address the threats to sDPS green sturgeon identified during the recovery planning process and based on knowledge gained since the threats assessment. If research or monitoring indicates that 1) future threats have been identified and are considered significant, or 2) threats currently ranked low become more important, then recovery criteria may be adjusted or developed at that time. By focusing on the threats detailed below, recovery (as defined above) of the sDPS is expected.

A. Present or Threatened Destruction, Modification, or Curtailment of a Species Habitat or Range

For Listing Factor A, each major threat category had threats ranked as High or Very High in at least one geographic area (Table 1). Threat-based criteria have been developed to address barriers to migration, water flow and temperature issues, and contaminants. For the remaining identified threats, criteria were not developed either because the tractability of the issue was outside the scope of a single species recovery plan or due to data insufficiency, or both. Research priorities have been developed to better understand the scope and severity of these threats.

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

Barriers to migration caused by impoundments were recognized as a High threat to adult sDPS in the SRB, with high data sufficiency. Large dams and flow dependent barriers constructed on the Sacramento, Feather, and Yuba rivers have restricted spawning and rearing areas for the sDPS by presenting a physical barrier to migration, an issue that was recognized as a main threat in the ESA listing decision and in the 2002 green sturgeon and 2016 sDPS status reviews.

Targets for meeting this criterion include passage over the boulder weir at Sunset Pumps on the Feather River, which is a flow-dependent barrier. The weir could either be removed, a low-flow gradient system could be constructed, or adequate flows could be provided through water management practices. Daguerre Point Dam on the Yuba River is also a target for modification or removal. On the mainstem Sacramento, volitional passage of green sturgeon in the Sacramento River upstream of the ACID Dam should be provided if areas upstream are identified as potential spawning habitat. If the census population of adult green sturgeon has not reached 3,000, all recovery actions have been successfully implemented, and appropriate time has been allocated for the population to reach the census population goal, additional options for expanding green sturgeon habitat will need to be identified and implemented.

Listing Factor A Recovery Criterion 2. Volitional passage is provided for adult green sturgeon through the Yolo and Sutter bypasses.

During some high flow events, adult green sturgeon enter the Yolo and Sutter bypasses and become stranded when the water recedes. CDFW has made efforts to rescue these fish in recent years but poaching of some sDPS fish has also likely occurred. Ameliorating the loss of sDPS spawning individuals due to poaching or stress will contribute to recovery. Addressing this issue will require structural changes as described in the next chapter.

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

The background literature referenced in Chapter I described the importance of flow and temperature for migration, egg development, and recruitment. While much is known from laboratory experiments using the nDPS and from field observations that suggest correlations between flow, temperature, and effective spawning or recruitment, uncertainty in the applicability of the information precludes it from being used to prescribe specific flow and temperature parameters necessary for sDPS recovery. It is further recognized that the Sacramento River watershed is a highly altered system that now must concurrently meet the needs of different species with potentially different habitat needs. Thus, an ecosystem approach is needed to meet this threat-based criterion. Before specific flow and temperature guidelines are provided, long term monitoring is necessary, as described in Chapter III. This has been incorporated into the monitoring program of this plan and can form the basis of recommended flow and temperature guidelines along with other sources of information.

Listing Factor A Recovery Criterion 4. Adult contaminant levels are below levels that are identified as limiting population maintenance and growth.

The threat posed by contaminants was recognized in all regions except the NM. While contaminants may impact survival, reproduction, and recruitment as suggested through laboratory studies and surrogate species, specific impacts to the sDPS have not been quantified in terms of how they might impede sDPS recovery. Given this, research and monitoring are first steps in meeting this threat-based criterion. Correlations can then be assessed regarding the impact of contaminants on population stability and growth and contaminant levels that limit population growth and maintenance can be identified.

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

No threats within this Listing Factor category were listed as High or Very High. Fisheries and poaching were considered as a Medium level threat in some areas, but any take of subadult or adult sDPS may limit population productivity. This threat-based criterion is aimed at reducing any take of sDPS that may still occur.

Listing Factor B Recovery Criterion 1. Take of adults and subadults through poaching and state, federal, and tribal fisheries is minimal and does not limit population persistence and growth.

As described in Chapter I, directed take of the sDPS is not permitted. Incidental take, post-release mortality, and poaching are thought to occur. This threat-based criterion is aimed at ensuring that governments monitor the take of the sDPS and minimize it to maintain population stability and growth as described in Chapter III. One way to address this criterion is to have Fishery Management and Evaluation Plans (FMEPs) in place demonstrating that incidental take does not significantly reduce the likelihood of survival or recovery (75 FR 30714, June 6, 2010).

C. Disease and Predation

No threat-based criteria were developed for this category. Disease was ranked as a High threat in the NM due to the potential transmission from native and non-native species and the potential effect of water quality on disease susceptibility. Since the extent of these potential threats in terms of limiting population growth and recovery is unknown, a research priority has been developed. Predation by marine mammals and non-native and native species was ranked as a High threat for at least one life stage in all areas except the NM. A recovery action is included focusing on predation by marine mammals. Given the limited information about predation by non-mammalian native species and non-native species, a research priority has been developed. Threat-based recovery criteria could be developed in the future should this research illustrate a necessity.

D. Inadequacy of Existing Regulatory Mechanisms

Threats considered under this listing factor have been identified in factor D of the previous section and additionally discussed under the other listing factors A through C and E.

E. Other Natural or Manmade Factors Affecting Its Continued Existence

Although several threats were identified under this listing factor, such as competition for habitat by native and non-native species and the potential threat of electromagnetic fields (EMF) from nearshore hydrokinetic facilities, there is currently not enough information to set threat-based recovery criteria. If future research provides information that suggests any of these threats are significant, then criteria may be developed at that time.

Recent laboratory research on entrainment of juvenile green sturgeon has shown that they are much more susceptible than either juvenile white sturgeon or salmonids, and therefore the following recovery criterion is provided.

Listing Factor E Recovery Criterion 1. Operation guidelines and/or fish screens are applied to water diversions in mainstem Sacramento, Feather, and Yuba rivers or San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment.

This recovery criterion requires research identifying the water diversions posing the greatest risk of entrainment of sDPS and the development of operations and screening criteria to limit entrainment and impingement. Implementation of these measures should reduce the threat to a point where it is not a limiting factor for juvenile recruitment. Further monitoring and population modeling will be necessary to estimate a potential level of entrainment that limits juvenile recruitment.

Chapter III. Recovery Strategy

This chapter presents the strategy for recovering the sDPS, including the primary focus of the recovery effort and how it addresses the most significant threats and biological needs of the species. This chapter also provides the rationale for the recommended recovery program actions.

Biological Needs, Significant and Potential Threats

The most critical biological needs of the sDPS as identified here are unobstructed passage, functional spawning and rearing habitat with appropriate water flow and temperature regimes, minimal risk of entrainment, take (e.g., poaching, stranding, fisheries bycatch), and enhanced understanding of the impacts of contaminants and climate change. These factors are the basis for the main recovery actions and are also the focus of research actions. Other significant or potential threats, including those posed by altered prey resources, predation, habitat suitability (turbidity, sediment load, substrate and water quality, competition for habitat) and disease, form the foundation for additional recovery actions and research priorities.

One of the greatest threats to the sDPS is the loss of spawning habitat due to the construction of dams in the Sacramento River system. Dams have limited available spawning habitats and, along with water management practices, have changed the flow and temperature profiles of the three major rivers that could be utilized by the sDPS for spawning (i.e., Sacramento, Feather, and Yuba rivers). Channel modification and water management practices have also affected sDPS rearing habitat within the SFBDE and likely impact recovery potential. Potential threats within CBE and NM habitats include those affecting habitat and prey resources. Uncertainty exists as to whether these factors are limiting recovery, particularly in reference to climate change. Other threats in CBE and NM habitats, such as incidental take through fisheries and predation, have the potential to cause the direct take of sDPS individuals.

Primary Focus and Justification of Recovery Strategy

Recovery plan actions and research priorities are summarized in Tables 2 and 3, respectively. Table 4 presents actions and research priorities organized by geographic area, life stage affected, and threat addressed. Specifics of the actions and research priorities are discussed in Chapter IV. Priorities (55 FR 24296, June 15, 1990) are defined as follows: Priority 1: An action that must be taken to prevent extinction or to identify those actions necessary to prevent extinction; Priority 2: An action that must be taken to prevent a significant decline in population numbers, habitat quality, or other significant negative impacts short of extinction; Priority 3: All other actions necessary to provide for full recovery of the species. This priority system (55 FR 24296, June 15, 1990) is used to compare actions between listed species inhabiting a similar region. No Priority 1 actions were identified for sDPS green sturgeon as, by definition, this species is not in imminent danger of extinction. As noted previously, threats ranked as Very High or High were not always assigned a recovery action. Rather, a research priority has been assigned in an effort to better characterize the threat and assist in the formulation of a future recovery action.

The main (Priority 2) recovery actions identified fall into six threat categories concerning passage, water flow and temperature, entrainment, take, contaminants, and climate change. Undertaking actions in these areas is expected to have the biggest impact in terms of sDPS recovery. These actions aim to restore spawning and rearing habitat in the SRB and SFBDE and limit mortality of individual juvenile and adult sDPS. The recovery strategy will incrementally restore habitat below Keswick, Oroville, and Englebright dams, provide volitional passage upstream of the boulder weir at Sunset Pumps on the Feather River and at Daguerre Point Dam on the Yuba River, and support adequate water flow and temperature on the Sacramento, Feather, and Yuba rivers while reducing stranding at Yolo and Sutter bypasses and other sources of take. Rearing habitats within the SFBDE will be studied with respect to suitability, with restoration options considered. Additional actions will focus on ameliorating the risk posed by entrainment in water diversions. Priority 3 recovery actions are identified in the areas of predation, non-point source sediment loading, and oil and chemical spills. Priority 3 actions can be implemented at any time but will likely have less of a direct and immediate impact in terms of meeting the recovery criteria. Some of these actions focus heavily on research in an effort to address data insufficiency and clarify actions to address the threat. All but one of the recovery action categories also includes research priorities, further emphasizing that monitoring and research is needed to understand the degree to which these threats impact population recovery and to identify recovery actions. A major challenge will be in providing conditions suitable for recovery while managing water resources for flood control, hydropower, water diversion, and conservation of other listed species.

Following implementation of the recovery actions, we expect to see an increase in the abundance, distribution, productivity, and diversity of sDPS green sturgeon such that the recovery criteria are met and the species can be delisted. Should recovery still appear hindered once recovery actions are implemented or should research reveal that additional actions are necessary, recovery actions and/or threat-based criteria will be adjusted or developed.

Table 2. Recovery Actions to recover the sDPS. Priority classification information can be found in Chapter IV.

1. Passage
1a (Priority 2) Provide upstream passage in the Feather River at the boulder weir located at Sunset Pumps.
1b (Priority 2) Until the Fremont Weir (Yolo Bypass) and Tisdale Weir (Sutter Bypass) are improved structurally to reduce stranding and to provide passage, ensure that any stranded green sturgeon are immediately relocated to the Sacramento River.
1c (Priority 2) Provide upstream passage at Daguerre Point Dam in the Yuba River.
1d (Priority 2) Construct a structure that will provide volitional passage for upstream migrating adults at Fremont and Tisdale weirs.
1e (Priority 2) Assess the feasibility of Sacramento Deep Water Ship Channel lock operation during the green sturgeon upstream migration period.
1f (Priority 2) Provide volitional upstream passage for green sturgeon at the Anderson-Cottonwood Irrigation District (ACID) Dam if a spawning habitat suitability study indicates that suitable upstream habitat is currently present or if upstream habitat is expected to become suitable in the foreseeable future.
2. Flow and Temperature
2a (Priority 2) Modify operations or facilities in the Oroville-Thermalito Complex to maintain suitable water temperatures and flows for spawning and recruitment throughout the sDPS spawning and rearing period in the Feather River.
2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.
2c (Priority 2) Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.
3. Entrainment
3a (Priority 2) Identify current and proposed water diversions posing significant risk to green sturgeon.
3b (Priority 2) Develop operations and/or screening guidelines.
3c (Priority 2) Apply operations or screening guidelines to diversions in the mainstem Sacramento, Feather, and Yuba rivers or San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment.
4. Take
4a (Priority 2) Reduce poaching in the Sacramento, Feather, and Yuba rivers and when the weirs overtop at the Yolo and Sutter bypasses through increased enforcement presence or improved relocation method.
4b. (Priority 2) Implement measures to reduce fisheries bycatch of green sturgeon in commercial and recreational fisheries and complete Fishery Management and Evaluation Plans for state fisheries encountering sDPS green sturgeon.
5. Contaminants
5a (Priority 2) Improve compliance and implementation of Best Management Practices (BMPs) to reduce input of point and non-point source contaminants within the Sacramento River Basin and San Francisco Bay Delta Estuary.
6. Habitat and Climate Change
6a (Priority 2) Forecast changes in temperatures in accessible spawning and rearing habitat in the Sacramento, Feather, and Yuba rivers for the next century. Use available lab-based tolerances and optima from nDPS as well as sDPS field data to assess the viability of spawning and rearing habitat over forecasted temperature change.
6b (Priority 2) Forecast temperature changes in CBE and NM habitats and potential response of the sDPS.
7. Predation
7a (Priority 3) Develop actions to reduce predation on sDPS green sturgeon in areas where high rates of predation occur based on an evaluation of the severity of marine mammal predation on sDPS green sturgeon.
8. Sediment
8a (Priority 3) Improve compliance and implementation of BMPs to reduce input of non-point source sediment within the upper Sacramento River Basin.
9. Oil and Chemical Spills
9a (Priority 3) Assess efficacy of oil and chemical spill response plans in the sDPS range in minimizing potential adverse effects to green sturgeon and develop updated plans as necessary.

Table 3. Research Priorities to be addressed to recover the sDPS. Priority classification information can be found in Chapter IV.

1. Passage
1a (Priority 3) Conduct research to assess migration of green sturgeon in the Sacramento Deep Water Ship Channel and Port of Sacramento (i.e., upstream locks).
1b (Priority 3) Conduct research to determine the effects on green sturgeon migration from the operations of the Delta Cross Channel gates.
2. Flow and Temperature
2a (Priority 2) Evaluate the effects of habitat modification and/or restoration (e.g., levee alteration, channel reconnection, floodplain connectivity measures) on green sturgeon recruitment and growth.
2b (Priority 3) Determine the effects of water management on green sturgeon habitat in the CBEs and consequent effects, if any, on individual growth and survival.
3. Entrainment
3a (Priority 3) Conduct research to determine the impacts of hydrokinetic facilities, especially those using turbines.
4. Take
4a (Priority 2) Conduct research to estimate the annual level of mortality of sDPS green sturgeon from poaching.
4b (Priority 2) Conduct research to develop an estimate of green sturgeon immediate and post-release mortality and sub-lethal effects from incidental capture in fisheries (e.g., gillnet, hook and line fisheries (CBE); coastal trawl fisheries (NM)).
5. Contaminants
5a (Priority 2) Conduct research to identify contaminants and contaminant concentrations in all life of stages green sturgeon and their prey base.
5b (Priority 2) Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base.
6. Habitat and Climate Change
6a (Priority 3) Conduct research to determine how native and non-native species compete with green sturgeon for habitat.
6b (Priority 3) Conduct research to determine the effect of water quality, including anoxic conditions, on habitat use of green sturgeon.
6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
7. Predation
7a (Priority 3) Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.
8. Sediment
8a (Priority 2) Conduct research to evaluate sDPS spawning substrate suitability in the Sacramento, Feather, and Yuba rivers.
8b (Priority 3) Conduct research on the effects of changes in turbidity and sediment load on green sturgeon habitat in the CBEs and consequent effects, if any on individual growth and survival.
9. Disease
9a (Priority 3) Include condition/health study in long-term green sturgeon monitoring to determine potential risk of disease to the sDPS.

Table 4. Recovery Actions (RA) and Research Priorities (RP) along with threat category and life stage organized by geographic region. 4a. Sacramento River Basin for eggs and larvae/juveniles, 4b. Sacramento River Basin for adults/subadults, 4c. San Francisco Bay Delta Estuary for juveniles, adults, and subadults, 4d. Coastal Bays and Estuaries, 4e. Nearshore Marine. Specific threats ranked Very High and High are highlighted in red and yellow, respectively. Grey boxes indicate the threat was not relevant to the area and/or life stage and was not ranked. Acronyms: APB: Altered Prey Base, AS: Altered Sediment, AT: Altered Turbidity, AWF: Altered Water Flow, AWT: Altered Water Temperature, BM: Barriers to Migration, C: Contaminants, CH: Competition for Habitat, D: Disease, DM: Water Depth Modification, LWF: Loss of Wetland Function, P: Predation, T: Take in Listing Factor C "Overutilization", TO: Take in Listing Factor E "Other Factors".

4a. Sacramento River Basin Specific Threats (Threat Category)	**Threat Ranking Eggs**	**Threat Ranking Larvae/ Juveniles**	**Identified Recovery Action or Research Priority**
Impoundments (AWT)	High	High	RA2a (Priority 2) Modify operations or facilities in the Oroville-Thermalito Complex to maintain suitable water temperatures and flows for spawning and recruitment throughout the sDPS spawning and rearing period in the Feather River. RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment. RA2c (Priority 2) Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.
Sacramento River Temperature Management (AWT)	Medium	Medium	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.
Impoundments and Upstream Diversions (AWF)	Low	Low	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment. RA2c (Priority 2) Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.

4a. Sacramento River Basin Specific Threats (Threat Category)	Threat Ranking Eggs	Threat Ranking Larvae/ Juveniles	Identified Recovery Action or Research Priority
Entrainment at water diversions (TO)		Medium	RA3a (Priority 2) Identify current and proposed water diversions posing significant risk to green sturgeon. RA3b (Priority 2) Develop operations and/or screening guidelines. RA3c (Priority 2) Apply operations or screening guidelines to diversions in the mainstem Sacramento, Feather, and Yuba rivers or San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment.
Point and Non-point source contaminants (C)	High	High	RA5a (Priority 2) Improve compliance and implementation of Best Management Practices (BMPs) to reduce input of point and non-point source contaminants within the Sacramento River Basin and San Francisco Bay Delta Estuary. RP5a (Priority 2) Conduct research to identify contaminants and contaminant concentrations in all life stages of green sturgeon and their prey base. RP5b (Priority 2) Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base.
Global climate change (AWT)	Medium	High	RA6a (Priority 2) Forecast changes in temperatures in accessible spawning and rearing habitat in the Sacramento, Feather, and Yuba rivers for the next century. Use available lab-based tolerances and optima from nDPS as well as sDPS field data to assess the viability of spawning and rearing habitat over forecasted temperature change.
Non-native species (APB)		High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Global climate change (APB)		High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Native and non-native species (CH)	High	High	RP6a (Priority 3) Conduct research to determine how native and non-native species compete with green sturgeon for habitat.
Native and non-native species (P)	High	Medium	RP7a (Priority 3) Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.

4b. Sacramento River Basin Specific Threats (Threat Category)	Threat Ranking Adults/ Subadults	Identified Recovery Action or Research Priority
Impoundments (BM)	High	RA1a (Priority 2) Provide upstream passage in the Feather River at the boulder weir located at Sunset Pumps. RA1c (Priority 2) Provide upstream passage at Daguerre Point Dam in the Yuba River. RA1f (Priority 2) Provide volitional upstream passage for green sturgeon at the Anderson-Cottonwood Irrigation District (ACID) Dam if a spawning habitat suitability study indicates that suitable upstream habitat is currently present or if upstream habitat is expected to become suitable in the foreseeable future.
Bypasses (BM)	Medium	RA1b (Priority 2) Until the Fremont Weir (Yolo Bypass) and Tisdale Weir (Sutter Bypass) are improved structurally to reduce stranding and to provide passage, ensure that any stranded green sturgeon are immediately relocated to the Sacramento River. RA1d (Priority 2) Construct structures that will provide volitional passage for upstream migrating adults at Fremont and Tisdale weirs.
Impoundments (AWT)	Medium	RA2a (Priority 2) Modify operations or facilities in the Oroville-Thermalito Complex to maintain suitable water temperatures and flows for spawning and recruitment throughout the sDPS spawning and rearing period in the Feather River. RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment. RA2c (Priority 2) Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.
Sacramento River temperature management (AWT)	Medium	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.
Impoundments (AWF)	Medium	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment. RA2c (Priority 2) Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.

4b. Sacramento River Basin Specific Threats (Threat Category)	Threat Ranking Adults/ Subadults	Identified Recovery Action or Research Priority
Poaching (T)	Medium	RA4a (Priority 2) Reduce poaching in the Sacramento, Feather, and Yuba rivers and when the weirs overtop at the Yolo and Sutter bypasses through increased enforcement presence or improved relocation methods. RP4a (Priority 2) Conduct research to estimate the annual level of mortality of sDPS green sturgeon from poaching.
Point and Non-point source contaminants (C)	High	RA5a (Priority 2) Improve compliance and implementation of Best Management Practices (BMPs) to reduce input of point and non-point source contaminants within the Sacramento River Basin and San Francisco Bay Delta Estuary. RP5a (Priority 2) Conduct research to identify contaminants and contaminant concentrations in all life stages of green sturgeon and their prey base. RP5b (Priority 2) Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base.
Global climate change (AWT)	High	RA6a (Priority 2) Forecast changes in temperatures in accessible spawning and rearing habitat in the Sacramento, Feather, and Yuba rivers for the next century. Use available lab-based tolerances and optima from nDPS as well as sDPS field data to assess the viability of spawning and rearing habitat over forecasted temperature change.
Non-point source sediment (DM)	High	RA8a (Priority 3) Improve compliance and implementation of BMPs to reduce input of non-point source sediment within the upper Sacramento River Basin. RP8a (Priority 2) Conduct research to evaluate sDPS spawning substrate suitability in the Sacramento, Feather, and Yuba rivers.

4c. San Francisco Bay Delta Estuary Specific Threats (Threat Category)	Threat Ranking Juveniles	Threat Ranking Adults/ Subadults	Identified Recovery Action or Research Priority
In-water Structures (BM)	Low	Low	RA1e (Priority 2) Assess the feasibility of Sacramento Deep Water Ship Channel lock operation during the green sturgeon upstream migration period. RP1a (Priority 3) Conduct research to assess migration of green sturgeon in the Sacramento Deep Water Ship Channel and Port of Sacramento (i.e., upstream locks). RP1b (Priority 3) Conduct research to determine the effects on green sturgeon migration from the operations of the Delta Cross Channel gates.
Impoundments (AWF)	Very High	High	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.
Upstream Diversions (AWF)	High	High	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.
Channel Control Structures (AWF)	Very High	Very High	RA2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment. RP2a (Priority 2) Evaluate the effects of habitat modification and/or restoration (e.g., levee alteration, channel reconnection, floodplain connectivity measures) on green sturgeon recruitment and growth.
Entrainment at Water Diversion (TO)	Low	Low	RA3a (Priority 2) Identify current and proposed water diversions posing significant risk to green sturgeon. RA3b (Priority 2) Develop operations and/or screening guidelines. RA3c (Priority 2) Apply operations or screening guidelines to diversions in the mainstem Sacramento, Feather, and Yuba rivers or San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment. RP3a (Priority 3) Conduct research to determine the impacts of hydrokinetic facilities, especially those using turbines.
Non-point Source Contaminants (C, APB)	High	Medium	RA5a (Priority 2) Improve compliance and implementation of Best Management Practices (BMPs) to reduce input of point and non-point source contaminants within the Sacramento River Basin and San Francisco Bay Delta Estuary. RP5a (Priority 2) Conduct research to identify contaminants and contaminant concentrations in all life stages of green sturgeon and their prey base. RP5b (Priority 2) Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base. RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.

4c. San Francisco Bay Delta Estuary Specific Threats (Threat Category)	Threat Ranking Juveniles	Threat Ranking Adults/ Subadults	Identified Recovery Action or Research Priority
Marine Mammals (P)	Medium	High	RA7a (Priority 3) Develop actions to reduce predation on sDPS green sturgeon in areas where high rates of predation occur based on an evaluation of the severity of marine mammal predation on sDPS green sturgeon.
Native and Non-native Species (CH)	Medium		RP6a (Priority 3) Conduct research to determine how native and non-native species compete with green sturgeon for habitat.
Global Climate Change (APB)	High	High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Non-native Species (APB)	Medium	Medium	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Native Species (P)	High	High	RP7a (Priority 3) Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.
Non-native Species (P)	High	Medium	RP7a (Priority 3) Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.

4d. Coastal Bay & Estuaries Specific Threats (Threat Category)	Threat Ranking Adults/ Subadults	Identified Recovery Action or Research Priority
Global Climate Change (AWT)	Very High	RA6b (Priority 2) Forecast temperature changes in CBE and NM habitats and potential response of the sDPS.
Marine Mammals (P)	High	RA7a (Priority 3) Develop actions to reduce predation on sDPS green sturgeon in areas where high rates of predation occur based on an evaluation of the severity of marine mammal predation on sDPS green sturgeon.
Impoundments (AWF, AWT)	High	RP2b (Priority 3) Determine the effects of water management on green sturgeon habitat in the CBEs and consequent effects, if any, on individual growth and survival.
Impoundments (AT, AS)	High	RP8b (Priority 3) Conduct research on the effects of turbidity and sediment load changes on green sturgeon habitat in the CBEs and consequent effects, if any, on individual growth and survival.
Hydrokinetic project entrainment (TO)	Low	RP3a (Priority 3) Conduct research to determine the impacts of hydrokinetic facilities, especially those using turbines.
Fisheries (T)	Medium	RA4b (Priority 2) Implement measures to reduce fisheries bycatch of green sturgeon in commercial and recreational fisheries and complete Fishery Management and Evaluation Plans for state fisheries encountering sDPS green sturgeon. RP4b (Priority 2) Conduct research to develop an estimate of green sturgeon immediate and post-release mortality and sub-lethal effects from incidental capture in fisheries (e.g., gillnet, hook and line fisheries (CBE); coastal trawl fisheries (NM)).
Point-source Contaminants (C)	Medium	RP5a (Priority 2) Conduct research to identify contaminants and contaminant concentrations in all life stages of green sturgeon and their prey base. RP5b (Priority 2) Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base.
Non-native Species (APB)	Very High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Global Climate Change (APB)	High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Non-native Species (LWF)	High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Water Quality (BM)	High	RP6b (Priority 3) Conduct research to determine the effect of water quality, including anoxic conditions, on habitat use by green sturgeon.
Native & non-native Species (CH)	High	RP6a (Priority 3) Conduct research to determine how native and non-native species compete with green sturgeon for habitat.
Native Species (P)	High	RP7a (Priority 3) Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.
Oil and Chemical Spills (C)	High	RA9a (Priority 3) Assess efficacy of oil and chemical spill response plans in the sDPS range in minimizing potential adverse effects to green sturgeon and develop updated plans as necessary.

4e. Nearshore Marine - Specific Threats (Threat Category)	Threat Ranking Adults/ Subadults	Identified Recovery Action or Research Priority
Global climate change (AWT)	High	RA6b (Priority 2) Forecast temperature changes in CBE and NM habitats and potential response of the sDPS.
Water quality, Non-native species (D)	High	RP9a (Priority 3) Include condition/health study in long-term green sturgeon monitoring to determine potential risk of disease to the sDPS.
Hydrokinetic project entrainment (TO)	Low	RP3a (Priority 3) Conduct research to determine the impacts of hydrokinetic facilities, especially those using turbines.
Fisheries (TO)	Medium	RA4b (Priority 2) Implement measures to reduce fisheries bycatch of green sturgeon in commercial and recreational fisheries and complete Fishery Management and Evaluation Plans for state fisheries encountering sDPS green sturgeon. RP4b (Priority 2) Conduct research to develop an estimate of green sturgeon immediate and post-release mortality and sub-lethal effects from incidental capture in fisheries (e.g., gillnet, hook and line fisheries (CBE); coastal trawl fisheries (NM)).
Native and non-native species (CH)	High	RP6a (Priority 3) Conduct research to determine how native and non-native species compete with green sturgeon for habitat.
Non-native species (APB)	Very High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.
Global climate change (APB)	High	RP6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.

Schedule

The schedule for implementing the actions in this recovery plan will depend on many factors such as staffing and funding. Implementation of recovery plans for other listed species may also provide an indirect benefit to the sDPS and affect the timing of recovery. Upon approval of this recovery plan, the following activities should be implemented, as guided by the recovery actions and research priorities described in Chapter IV. These programs should be flexible to incorporate new information as it becomes available.

1) Implementing recovery actions addressing passage, temperature and flow, entrainment, and poaching.
2) Developing the following:
   a) Research plan to fill data gaps regarding threats limiting green sturgeon recovery, beginning with the research-oriented recovery actions and the research priorities identified here;
   b) Monitoring plan to assess the progress of recovery actions and the attainment of demographic and threat-based recovery criteria. Monitoring plan priorities are discussed later in this document. An overview of current and historical sDPS green sturgeon monitoring and research, including recommendations for potential studies tracking demographic recovery criteria, is provided in Heublein et al. (2017b);
   c) Education, outreach, and stakeholder engagement program to facilitate awareness and support and secure funding for implementing this recovery plan. Recovery will require working together with a diverse array of stakeholders, including federal, state, and local agencies, non-profit organizations, and Tribes, to carry out the recovery actions outlined in this plan. The public will need to be engaged by raising their awareness of green sturgeon conservation needs and protections.
3) Implementing remaining recovery actions and research priorities not implemented in 1 and 2 above.

Based on results from implementation, NMFS may refine the recovery criteria or revise or re-prioritize recovery actions. For example, if indices of recruitment to the juvenile life stage do not show a net positive trend within 15 years after restoring adequate habitat in the Sacramento, Feather, and Yuba rivers, then additional spawning and rearing habitat may be needed elsewhere or other activities that increase juvenile productivity may be needed. Watersheds that might have once provided spawning habitat based on historical conditions (i.e., Bear River, American River, and Russian River) could be considered. Assessments of these rivers would first need to be conducted to determine if they contain suitable spawning/rearing habitat or the geomorphic conditions needed to create that habitat. While sDPS currently utilize the lower San Joaquin River, this river is not a main focus of the recovery plan due to the lack of historical records indicating that the sDPS once spawned in the system. An increase in sDPS reports or evidence of spawning migratory behavior in the San Joaquin River, particularly in higher river reaches, would merit consideration of establishment of a spawning population there as a recovery goal.

Chapter IV. Recovery Program

This chapter presents prioritized recovery actions for the threats that limit recovery, with a focus on threats ranked as High or Very High. If the recovery criteria have not been met after implementing recovery actions in this plan, these threats may be revisited. Since research is needed to inform many recovery actions, a research plan should be developed during the initial phase of implementation. The supporting programs of monitoring and outreach should also be developed during the initial phase.

The following outlines the 20 recommended recovery actions and 16 research priorities. The first 17 recovery actions, classified into the four categories of passage, flow and temperature, entrainment, take, contaminants and habitat and climate change are assigned priority 2; they represent the most significant actions necessary to recover the sDPS. The remaining three priority 3 recovery actions are less of a priority given their likely impact on recovery. Associated research priorities are described within each category for ease of understanding and because research should be implemented immediately. That said, the listing of research priorities sequentially does not confer prioritization. It is also recognized that the research priorities will not likely be accomplished along with the recovery actions. Research with potentially high management or recovery value is given a priority of 2. Threat categories, areas, and life stages are given in the headings before the actions and research are described. The subsequent sections detailing monitoring and outreach are also necessary components of this plan. Priority rankings have also been given to actions within these sections.

Addresses Listing Factor A and D - Habitat Destruction, Modification, or Curtailment of Habitat or Range and Inadequacy of Existing Regulatory Mechanisms

Barriers to Migration (SRB, SFBDE adults/subadults)

Recovery Action 1a (Priority 2) Provide upstream passage in the Feather River at the boulder weir located at Sunset Pumps.

There are several potential solutions available to address the passage barrier on the Feather River at Sunset Pumps' boulder weir. The boulder weir at Sunset Pumps could potentially be removed if the diversion point was relocated to the Thermalito Afterbay. Alternatively, a fish way or low-flow gradient system similar to the one located near the Glenn Colusa Irrigation District's water diversion intake on the Sacramento River near Hamilton City could be constructed in order to provide both upstream and downstream passage of green sturgeon at the boulder weir. If none of these potential solutions are implemented, then research is needed to better determine the minimum flow required for the sDPS to pass at this site.

Recovery Action 1b (Priority 2) Until the Fremont Weir (Yolo Bypass) and Tisdale Weir (Sutter Bypass) are improved structurally to reduce stranding and to provide passage, ensure that any stranded green sturgeon are immediately relocated to the Sacramento River.

Efforts are needed to reduce stranding time. Fish should continue to be relocated from the bypasses into the Sacramento River until the weirs are structurally improved and provide passage.

Recovery Action 1c (Priority 2) Provide upstream passage at Daguerre Point Dam in the Yuba River.

Volitional fish passage at Daguerre Point Dam is the preferred approach for restoring access to historical green sturgeon habitat and establishing an additional spawning location in the Yuba River watershed. Although modification may meet this standard, there are no current examples of a functioning adult green sturgeon passage structure. Dam removal is the most preferred approach because it provides unimpeded passage for adult sturgeon as well as numerous aquatic species and best restores the natural processes of the river ecosystem. The impact of dam removal or modification on all anadromous species should be studied during the removal scoping and planning phase. It is recognized that habitat improvements may need to be made once sturgeon passage is addressed at Daguerre Point Dam, the specifics of which will need to be determined after the response of the sDPS to passage improvement or restoration is evaluated.

Recovery Action 1d (Priority 2) Construct a structure that will provide volitional passage for upstream migrating adults at Fremont and Tisdale weirs.

The United States Bureau of Reclamation (USBR) and the California Department of Water Resources (CDWR) have proposed a plan to address this issue in the Yolo Bypass (USBR and CDWR 2012). Plans should be developed and implemented to address this issue at the Sutter Bypass as well. Once these major structural changes are made, additional changes may be needed downstream of the weirs and throughout the bypasses to address features such as scour pits and ponds if green sturgeon strand in these areas when flows recede after flooding.

Recovery Action 1e (Priority 2) Assess the feasibility of Sacramento Deep Water Ship Channel lock operation during the green sturgeon upstream migration period.

Intermittent opening of the locks during the green sturgeon spawning migration may address potential passage impediment. While presently available information does not show that green sturgeon are impacted by the Deep Water Ship Channel, this may be an artefact of limitations in tagging, receiver arrays, or data analysis. Operation of the lock will also improve habitat connectivity for multiple species.

Recovery Action 1f (Priority 2) Provide volitional upstream passage for green sturgeon at the Anderson-Cottonwood Irrigation District (ACID) Dam if a spawning habitat suitability study indicates that suitable upstream habitat is currently present or if upstream habitat is expected to become suitable in the foreseeable future.

A habitat assessment, using parameters from field and lab-based literature and modeling exercises should be undertaken to assess current habitat suitability and future suitability given climate change. If the sDPS is not determined as moving forward towards recovery after other recovery actions are implemented, and habitat above ACID Dam is deemed unsuitable because of cold-water releases, water management alterations providing suitable habitat for the sDPS between ACID and Keswick dams should be evaluated.

Research Priority 1a (Priority 3) Conduct research to assess migration of green sturgeon in the Sacramento Deep Water Ship Channel and Port of Sacramento (i.e., upstream locks).
Research Priority 1b (Priority 3) Conduct research to determine the effects on green sturgeon migration from the operations of the Delta Cross Channel gates.

New research and/or analysis of telemetry data is needed to understand if these structures prevent or delay passage of adult green sturgeon or have a potential effect on juvenile migration and rearing habitat accessibility.

Addresses Listing Factor A and D - Habitat Destruction, Modification, or Curtailment of Habitat or Range and Inadequacy of Existing Regulatory Mechanisms

Altered Water Flow, Altered Water Temperature (SRB eggs, larvae/juveniles, adults/subadults; SFBDE juveniles, adults/subadults)

Altered Water Flow, Altered Water Temperature, Altered Turbidity, Altered Sediment (CBE adults/subadults) (RP2b only)

Recovery Action 2a (Priority 2) Modify operations or facilities in the Oroville-Thermalito Complex to maintain suitable water temperatures and flows for spawning and recruitment throughout the sDPS spawning and rearing period in the Feather River.

Evaluation of water operations needed to provide water temperatures and flows suitable for sDPS reproduction while also serving agriculture and hydropower is a necessary first step. One possible method to lower the water temperature in the Feather River would be to increase cold water releases from the Thermalito Diversion Pool (directly downstream of Oroville Dam) into the Feather River. Increasing irrigation diversions directly from the Thermalito Afterbay would further reduce the amount of warm water entering the Feather River at the Thermalito Afterbay Outlet. This scenario may also be consistent with measures for achieving Recovery Action 1a (relocating the Sunset Pumps diversion point to Thermalito Afterbay to address passage) although other solutions may be more favorable. Analyzing trade-offs should be a focus of efforts to achieve this action.

Recovery Action 2b (Priority 2) Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.

This recovery action addresses the management of impoundments, water diversions, and temperature control in the SRB. The recovery action would require use of information from long-term monitoring of the sDPS to determine flow and temperature targets rather than relying on laboratory studies and studies of surrogate species.

Recovery Action 2c (Priority 2) Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.

Investigation into inter-annual green sturgeon spawning success on the Feather River and downstream spawning range of the Sacramento River may identify temperature and flow thresholds associated with successful green sturgeon spawning. These potential flow and temperature thresholds could then be used to evaluate existing conditions on the Yuba River and the need for modifying water operations.

Research Priority 2a (Priority 2) Evaluate the effects of habitat modification and/or restoration (e.g., levee alteration, channel reconnection, floodplain connectivity measures) on green sturgeon recruitment and growth.
Research Priority 2b (Priority 3) Determine the effects of water management on green sturgeon habitat in the CBEs and consequent effects, if any, on individual growth and survival.

The population (e.g., recruitment) and individual (e.g., growth) impacts of existing and proposed channel margin, tidal wetland, and floodplain modification projects in the SFBDE should be evaluated. Furthermore, beneficial characteristics of tidal wetland and floodplain restoration projects in the SFBDE (e.g., forage, depth, flow, turbidity) should be identified to guide future projects. Research priorities regarding temperature and flow aim to understand how current in-water projects and water management practices impact the sDPS and refine future recovery actions. In the CBE, particularly the Columbia River estuary, testable hypotheses are needed that link changes in habitat through water management (e.g., changes in flow, temperature, turbidity, and sediment load) to growth and survival of sDPS green sturgeon.

Addresses Listing Factor D and E - Inadequacy of Existing Regulatory Mechanisms and Other Factors

Take (SRB larvae/juveniles, SFBDE juveniles for 3a, 3b, 3c and RP3a; SFBDE juveniles, adults/subadults, CBE, NM for RP3a)

Recovery Action 3a (Priority 2) Identify current and proposed water diversions posing significant risk to green sturgeon.
Recovery Action 3b (Priority 2) Develop operations and/or screening guidelines.
Recovery Action 3c (Priority 2) Apply operations or screening guidelines to diversions in the mainstem Sacramento, Feather, and Yuba rivers or San Francisco Bay Delta Estuary such that early life stage entrainment is below a level that limits juvenile recruitment.

Identifying the highest risk diversions to sDPS based on combined field and laboratory studies, developing operation and/or screening criteria, and finally applying these criteria to highest risk diversions in the Sacramento, Feather, and Yuba rivers and SFBDE will reduce loss of individual sDPS fish through entrainment. This will require monitoring and population modeling to determine a potential quantitative level of entrainment that limits juvenile recruitment.

Research Priority 3a (Priority 3) Conduct research to determine the impacts of hydrokinetic facilities, especially those using turbines.

This research priority concerns conducting new research on the risks posed by potential hydrokinetic facilities, particularly the impact of facilities using turbines. Such research would inform recovery actions and permitting decisions.

Addresses Listing Factor B and D - Overutilization for Recreational, Commercial, Scientific or Educational Purposes and Inadequacy of Existing Regulatory Mechanisms

Take (SRB, SFBDE adults/subadults for 4a, RP 4a; CBE, NM for RP4b)

Recovery Action 4a (Priority 2) Reduce poaching in the Sacramento, Feather, and Yuba rivers and when the weirs overtop at the Yolo and Sutter bypasses through increased enforcement presence or improved relocation methods.

This recovery action aims to reduce poaching, particularly when sDPS green sturgeon are stranded in the bypasses.

Recovery Action 4b (Priority 2) Implement measures to reduce fisheries bycatch of green sturgeon in commercial and recreational fisheries and complete Fishery Management and Evaluation Plans for state fisheries encountering sDPS green sturgeon**.**
Research Priority 4a (Priority 2) Conduct research to estimate the annual level of mortality of sDPS green sturgeon from poaching.
Research Priority 4b (Priority 2) Conduct research to develop an estimate of green sturgeon immediate and post-release mortality and sub-lethal effects from incidental capture in fisheries (e.g., gillnet, hook and line fisheries (CBE); coastal trawl fisheries (NM)).

The recovery action aims to increase knowledge of the impacts of fisheries bycatch and minimize take of sDPS due to incidental mortality. Completion of FMEPs will ensure that green sturgeon bycatch in state fisheries will not significantly reduce the likelihood of survival or recovery of the sDPS (75 FR 30714, June 6, 2010). The research priorities here are of potentially high management and recovery value in estimating poaching levels and reducing bycatch mortality in fisheries.

Addresses Listing Factor A and D - Habitat Destruction, Modification, or Curtailment of Habitat or Range and Inadequacy of Existing Regulatory Mechanisms

Altered Prey Base, Contaminants (SRB, SFBDE all life stages, CBE for RP5a, RP5b)

Recovery Action 5a (Priority 2) Improve compliance and implementation of Best Management Practices (BMPs) to reduce input of point and non-point source contaminants within the Sacramento River Basin and San Francisco Bay Delta Estuary.

Best Management Practices (BMPs) are measures either self-imposed or mandated by government (e.g., Federal, state, county, city) to reduce environmental impacts of activities such as wastewater treatment, agriculture, logging, mining, and manufacturing. In this plan, the BMPs referenced primarily involve water quality. For this recovery action, BMPs that reduce contaminants in wastewater, stormwater, and agricultural effluent that enter the Central Valley Rivers and SFBDE should be improved with respect to compliance and implementation. Enhancing treatment or adding riparian buffers could be a means of reducing contaminant exposure to all life stages of sDPS green sturgeon.

Research Priority 5a (Priority 2) Conduct research to identify contaminants and contaminant concentrations in all life stages of green sturgeon and their prey base.
Research Priority 5b (Priority 2) Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base.

These research priorities aim to better specify the contaminants posing a risk to the sDPS and its prey base so as to refine the recovery actions. The research has the potential to impact recovery criteria and actions into the future and should include investigation of chemicals used in CBE environments to control burrowing shrimp.

Addresses Listing Factor A - Habitat Destruction, Modification, or Curtailment of Habitat or Range

Altered Water Temperature (SFDBE all life stages for 6a; CBE, NM for 6b), Altered Prey Base (SRB larvae/juveniles, SFBDE for all life stages, CBE, NM for RP6c), Barriers to Migration (CBE for RP6b), Loss of Wetland Function (CBE for RP6c)

Addresses Listing Factor E - Other Factors

Competition for Habitat (SRB eggs, larvae/juvenile, SFBDE juveniles, CBE, NM for RP6a)

Recovery Action 6a (Priority 2) Forecast changes in temperatures in accessible spawning and rearing habitat in the Sacramento, Feather, and Yuba rivers for the next century. Use available lab-based tolerances and optima from nDPS as well as sDPS field data to assess the viability of spawning and rearing habitat over forecasted temperature change.
Recovery Action 6b (Priority 2) Forecast temperature changes in CBE and NM habitats for the next century and potential response of the sDPS.

These recovery actions aim to forecast specific responses to climate changes in terms of available habitat and prey and altered behavior across the range of the sDPS. Some of this work will be better supported with completion of RP6a and RP6c below.

Research Priority 6a (Priority 3) Conduct research to determine how native and non-native species compete with green sturgeon for habitat.
Research Priority 6b (Priority 3) Conduct research to determine the effect of water quality, including anoxic conditions, on habitat use of green sturgeon.
Research Priority 6c (Priority 3) Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.

Research on the sDPS prey base and the impact of non-native species and climate change and on how water quality impacts migration would inform recovery efforts in the future.

Addresses Listing Factor C - Disease and Predation

Predation (SFBDE all life stages, CBE for 7a; SRB eggs, larvae/juveniles, SFBDE, CBE for RP7a)

Recovery Action 7a (Priority 3) Develop actions to reduce predation on sDPS green sturgeon in areas where high rates of predation occur based on an evaluation of the severity of marine mammal predation on sDPS green sturgeon.
Research Priority 7a (Priority 3) Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.

An evaluation of the severity of marine mammal and native and non-native species predation would better direct recovery efforts in the future.

Addresses Listing Factor A and D - Habitat Destruction, Modification, or Curtailment of Habitat or Range and Inadequacy of Existing Regulatory Mechanisms

Altered Turbidity, Altered Sediment (CBE for RP8b)
Water Depth Modification (SRB subadults/adults for 8a, RP8a)

Recovery Action 8a (Priority 3) Improve compliance and implementation of BMPs to reduce input of non-point source sediment within the upper Sacramento River Basin.

See BMP description in Recovery Action 5a above. The use of better land use practices, such as the creation of riparian buffers, use of "greener" bank stabilization technologies, improving timber harvest practices, such as replanting following fires, and improving road building practices on both public and private land, should result in reducing sediment runoff.

Research Priority 8a (Priority 2) Conduct research to evaluate sDPS spawning substrate suitability in the Sacramento, Feather, and Yuba rivers.
Research Priority 8b (Priority 3) Conduct research on the effects of changes in turbidity and sediment load on green sturgeon habitat in the CBEs and consequent effects, if any on individual growth and survival.

These research priorities aim to understand how sediment load is impacting the sDPS in terms of habitat in the SRB and CBEs.

Addresses Listing Factor A and D - Habitat Destruction, Modification, or Curtailment of Habitat or Range and Inadequacy of Existing Regulatory Mechanisms

Contaminants (Oil and Chemical Spills) (CBE)

Recovery Action 9a (Priority 3) Assess efficacy of oil and chemical spill response plans in the sDPS range in minimizing potential adverse effects to green sturgeon and develop updated plans as necessary.

An assessment of oil and chemical response plans is needed to assess whether specific measures should be incorporated to minimize potential adverse effects to the sDPS. Should additional measures be necessary, plans should be updated.

Addresses Listing Factor C - Disease and Predation

Disease (NM)

Research Priority 9a (Priority 3) Include condition/health study in long-term green sturgeon monitoring to determine potential risk of disease to the sDPS.

Disease transmittal from native and non-native species, release of diseased fish from hatcheries, and reduced immunity from exposure to poor water quality, such as dead zones, are all potential impacts of this threat, and monitoring would better determine the risk posed.

Supporting Program - Monitoring

During the initial phase of recovery plan implementation, the three supporting programs of Research, Monitoring, and Outreach/Education will need to be developed. The Research program should focus on the priorities identified above. Monitoring activities should be initiated immediately, or be continued if they are already in place, in order to provide baseline information and to determine progress toward delisting. A great deal of information regarding current monitoring schemes in the SRB and SFBDE can be found in Heublein et al. (2017a, 2017b). Below, monitoring schemes are only briefly described as the specifics of how monitoring may be conducted may be at the discretion of the researcher or dependent upon the scale of funding.

Monitoring Priority 1 (Priority 2) *Monitor the annual abundance of sDPS green sturgeon spawning adults in the Sacramento, Feather, and Yuba rivers.* Assessments of the number of green sturgeon spawning in the SRB are currently conducted each spring/summer by NMFS and CDFW and should continue and possibly be expanded. Monitoring programs should be altered to allow identification of variations in run timing (e.g., assessing whether spring and fall runs exist) if an analysis of existing telemetry data proves inadequate to address this.

Monitoring Priority 2 (Priority 2) *Monitor trends in the annual production of larval sDPS green sturgeon from the Sacramento, Feather, and Yuba rivers.* In order to determine if green sturgeon are successfully reproducing in the Sacramento, Feather, and Yuba rivers, annual surveys to determine the production of larvae should continue. Surveys will need to change to focus on new habitat areas as they are opened up via recovery actions. These surveys need to be standardized to the extent that a net increase in larval production and progress towards this recovery criterion can be assessed.

Monitoring Priority 3 (Priority 2) *Monitor trends in the annual production and habitat use of juvenile sDPS green sturgeon in the SRB and SFBDE.*

Monitoring Priority 4 (Priority 2) *Monitor the population age structure (size classes) of sDPS green sturgeon once every five years.* Every five years, adult and subadult green sturgeon should be sampled from coastal bays and estuaries in order to determine if size classes are proportionately represented.

Monitoring Priority 5 (Priority 2) *Assess genetic diversity of spawning and juvenile sDPS green sturgeon annually, if possible, or for at least three consecutive years each ten-year period. Develop a system to assess effective population size of sDPS spawning adults.* A tissue sample should be collected from all adult and juvenile green sturgeon encountered in the SRB during research studies for genetic analysis to facilitate the diversity and effective population size analysis.

Monitoring Priority 6 (Priority 3) *Use telemetry to monitor sDPS use of estuaries and coastal environments.* Monitoring programs should be designed to provide a better understanding of fine-scale habitat use in estuaries given that such information is needed in analyzing the impacts of different estuarine and nearshore projects (e.g., aquaculture (e.g., in Humboldt Bay), dredging and disposal of dredge spoils (e.g., in the Columbia River and Umpqua estuary, Grays Harbor, Willapa, Tillamook, Coos, and Nehalem Bay)) on the sDPS and clarify in-water work windows and best management practices across estuaries. In addition, monitoring of the Eel and Klamath River estuaries should be considered given the potential use by the sDPS. Monitoring programs should be sensitive enough to provide the information needed to eventually detect behavioral differences and shifts in habitat use and migration patterns that may occur with climate change.

Monitoring Priority 7 (Priority 2) *Work cooperatively with fisheries that regularly encounter the sDPS to utilize these encounters as a source of monitoring data on recovery.* Existing fisheries data should also be analyzed to understand whether trend data can be assessed and, if necessary, how/if monitoring of fisheries could be changed to better gather data on the sDPS.

Monitoring Priority 8 (Priority 3) *Implement strategies in state, Federal, and tribal fisheries to monitor and reduce the take of green sturgeon in fisheries.*

Monitoring Priority 9 (Priority 2) *Implement long-term monitoring of contaminant levels in adults and compare to inter-annual spawning and recruitment to understand potential relationships between contaminant levels, reproduction, and recruitment.*

Monitoring Priority 10 (Priority 2) *Use eDNA or other methods to monitor unoccupied rivers/non-spawning population rivers for the presence of green sturgeon, particularly during summer months.* Priority rivers would be those more likely to have sDPS rather than nDPS (i.e., American, Bear, Russian, San Joaquin, Stanislaus, and Tuolumne rivers).

Supporting Programs - Education and Outreach

Education and outreach efforts should focus on user groups that may encounter green sturgeon and those that may be impacted by or could facilitate management practices that assist in the recovery of sDPS green sturgeon. As water use in the Central Valley requires balancing competing needs, outreach and education efforts targeting user groups and management agencies could facilitate an understanding of the needs of the sDPS. A presentation of the recovery plan aims, objectives, criteria and actions should be given to user groups and management agencies. Outreach efforts that focus on fishermen that may encounter the sDPS across its range should provide information on sDPS fishing regulations and the potential problems of post-release mortality and poaching. School groups should also be a target for outreach and education given the unique attributes of green sturgeon and the vehicle they provide for talking about environmental issues such as water availability, habitat modification, and drought.

The recovery plan presented here aims to restore habitat, reduce mortality, and address the major threats identified to facilitate the recovery of the sDPS. If after implementing the 20 recovery actions described above, the demographic recovery criteria have not been met, additional actions will need to be taken. Given that it will potentially take two decades to implement the above actions and meet demographic criteria, NMFS anticipates that a greater understanding of the factors affecting this species will be known in the future and thus recovery actions may be refined moving forward.

Implementation Schedule & Costs

Implementation of the plan in terms of action duration, partnering agencies and estimated costs is outlined in Table 5. Although candidate agencies for completing individual recovery actions have been identified based on authority, responsibility, and expertise, the listing of a partnering agency does not require the party to implement or secure funding for the action, as recovery actions are discretionary. Participating parties will benefit by being able to show in any funding request that specific work is for a recovery action that has been identified in an approved recovery plan. Section 7(a)(1) of the ESA directs all Federal agencies to use their authorities in furtherance of the purposes of the ESA, in this case by specifically addressing recovery actions for which they have been identified as a responsible party.

Implementation of recovery actions will require collaboration among many entities, including NMFS, other Federal agencies, and state and local agencies, as detailed in Table 5. As most recovery actions focus on California's Central Valley, staff from the NMFS' West Coast Region will likely have the biggest role in overseeing implementation of this plan. Collaboration between NMFS and other Federal (e.g., USBR, USFWS) and state agencies (e.g., CDFW and CDWR) will be imperative.

The estimated total cost of the recovery plan over 20 years is $237 million dollars, including actions, research, monitoring and education and outreach. Most actions should be scheduled to take place in the first five to ten years. Many of the most-costly recovery actions (e.g., barrier removal, increased enforcement, addressing entrainment at diversions) have multi-species benefits and may be covered under recovery efforts for other species. For example, the recovery plan for listed Central Valley salmonids (NMFS 2014) includes recovery actions designed to improve watershed-wide processes that will likely benefit sDPS green sturgeon by restoring natural ecosystem functions. Specific actions to improve Delta habitat, remove barriers, and reduce entrainment could aid in the recovery of the sDPS and reduce the sDPS recovery plan cost by $17 million.

It is anticipated that the recovery of sDPS green sturgeon is likely to be a long process. Restoring habitat by providing adequate water flow and temperature and addressing migration barriers is likely to take ten years or more. That said, interim measures will be and are already being taken to facilitate green sturgeon recovery. Due to green sturgeon's slow maturation and low recruitment rate, increases in abundance may take between three to four generations following an improvement of habitat conditions. Given a generation time for sDPS green sturgeon of approximately 22 years (IUCN Green Sturgeon Red List update, in preparation) a substantial increase in adult abundance in response to implemented habitat-based recovery actions may not be observed for 66-88 years. Funds will thus likely be needed to monitor adult abundance after the first 20 years, for a total additional overall cost of $25-40 million.

Table 5. Action duration, partnering agencies and estimated costs of the sDPS green sturgeon recovery plan. Costs were estimated through research on costed activities currently proposed that are the same or similar to those outlined. Zero cost projects are part of ongoing or proposed activities and programs.

Identifier	Area	Threat Addressed	Recovery Action	Priority	Recovery Partners	Duration (Years)	FY1-5	FY6-10	FY11-15	FY16-20	Total Cost (Thousands of Dollars) FY1-FY20
Recovery Action 1a	**SRB**	***Barriers to Migration***	**Provide upstream passage in the Feather River at the boulder weir located at Sunset Pumps.**	**2**	**CDWR, NMFS, other state and federal agencies**	**5**	**17,000**	**0**	**0**	**0**	**17,000**
Recovery Action 1b	**SRB**	***Barriers to Migration***	**Until the Fremont Weir (Yolo Bypass) and Tisdale Weir (Sutter Bypass) are improved structurally to reduce stranding and to provide passage, ensure that any stranded green sturgeon are immediately relocated to the Sacramento River.**	**2**	**CDFW, other state and federal agencies**	**10**	**500**	**500**	**0**	**0**	**1,000**
Recovery Action 1c	**SRB**	***Barriers to Migration***	**Provide upstream passage at Daguerre Point Dam in the Yuba River.**	**2**	**Army Corps, NMFS, state and other federal agencies**	**5**	**63,000**	**0**	**0**	**0**	**63,000**
Recovery Action 1d	**SRB**	***Barriers to Migration***	**Construct a structure that will provide volitional passage for upstream migrating adults at Fremont and Tisdale weirs.**	**2**	**USBR, CDWR, other state and federal agencies**	**5**	**0**	**0**	**0**	**0**	**0**
Recovery Action 1e	**SRB**	***Barriers to Migration***	**Assess the feasibility of Sacramento Deep Water Ship Channel lock operation during the green sturgeon upstream migration period.**	**2**	**NMFS, state and other federal agencies**	**20**	**25**	**25**	**25**	**25**	**100**
Recovery Action 1f	**SRB**	***Barriers to Migration***	**Provide volitional upstream passage for green sturgeon at the Anderson-Cottonwood Irrigation District (ACID) Dam if a spawning habitat suitability study indicates that suitable upstream habitat is currently present or if upstream habitat is expected to become suitable in the foreseeable future.**	**2**	**NMFS, ACID, state and other federal agencies**	**20**	**150**	**18,000**	**50**	**50**	**18,250**
Research Priority 1a	**SRB, SFBDE**	***Barriers to Migration***	**Conduct research to assess migration of green sturgeon in the Sacramento Deep Water Ship Channel and Port of Sacramento (i.e., upstream locks).**	**3**	**NMFS, CDFW, USFWS, other state and federal agencies, academic institutions**	**3**	**450**	**0**	**0**	**0**	**450**
Research Priority 1b	**SRB, SFBDE**	***Barriers to Migration***	**Conduct research to determine the effects on green sturgeon migration from the operations of the Delta Cross Channel gates.**	**3**	**NMFS, CDFW, USFWS, other state and federal agencies, academic institutions**	**5**	**0**	**450**	**0**	**0**	**450**
Recovery Action 2a	**SRB**	***Altered Water Flow, Altered Water Temperature***	**Modify operations or facilities in the Oroville-Thermalito Complex to maintain suitable water temperatures and flows for spawning and recruitment throughout the sDPS spawning and rearing period in the Feather River.**	**2**	**FERC, CDWR, other state and federal agencies, NGOs**	**5**	**125**	**0**	**0**	**0**	**125**

Identifier	Area	Threat Addressed	Recovery Action	Priority	Recovery Partners	Duration (Years)	FY1-5	FY6-10	FY11-15	FY16-20	Total Cost (Thousands of Dollars) FY1-FY20
Recovery Action 2b	**SRB, SFBDE**	***Altered Water Flow, Altered Water Temperature***	**Develop temperature and flow targets in accessible spawning, incubation, and rearing habitat through long-term monitoring of spawning, larvae, and juvenile distribution and recruitment.**	**2**	**NMFS, USBR, CDWR, other federal and state agencies**	**10**	**1,250**	**1,250**	**0**	**0**	**2,500**
Recovery Action 2c	**SRB**	***Altered Water Flow, Altered Water Temperature***	**Assess temperature and flow in the Yuba River based on suitable conditions for green sturgeon production in the Sacramento and Feather rivers. If necessary, study the feasibility of modifying water operations on the Yuba River to support spawning and recruitment.**	**2**	**CDWR/local water agencies, Army Corps (if structural), NMFS, CDFW, USFWS**	**5**	**0**	**0**	**250**	**0**	**250**
Research Priority 2a	**SFBDE**	***Altered Water Flow, Altered Water Temperature***	**Evaluate the effects of habitat modification and/or restoration (e.g., levee alteration, channel reconnection, floodplain connectivity measures) on green sturgeon recruitment and growth.**	**2**	**NMFS, USBR, state and other federal agencies, private landowners and companies**	**15**	**120**	**120**	**120**	**0**	**360**
Research Priority 2b	**CBE**	***Altered Water Flow, Altered Water Temperature, Altered Sediment, Altered Turbidity***	**Determine the effects of water management on green sturgeon habitat in the CBEs and consequent effects, if any, on individual growth and survival**	**3**	**State agencies, Army Corps, Bonneville Power Administration (Columbia River), USBR**	**4**	**0**	**120**	**120**	**0**	**240**
Recovery Action 3a	**SRB, SFBDE**	***Take (Entrainment in Water Diversions)***	**Identify current and proposed water diversions posing significant risk to green sturgeon.**	**2**	**NMFS, state and other federal agencies**	**2**	**250**	**0**	**0**	**0**	**250**
Recovery Action 3b	**SRB, SFBDE**	***Take (Entrainment in Water Diversions)***	**Develop operations and/or screening guidelines.**	**2**	**NMFS, state and other federal agencies**	**2**	**0**	**250**	**0**	**0**	**250**
Recovery Action 3c	**SRB, SFBDE**	***Take (Entrainment in Water Diversions)***	**Apply operations or screening guidelines to diversions in the mainstem Sacramento, Feather, and Yuba rivers or SFBDE such that early life stage entrainment is below a level that limits juvenile recruitment.**	**2**	**CDFW, USFWS, NMFS, Army Corps, CDWR/water agencies, CDPR, NGOs, private landowners and companies**	**10**	**0**	**8,000**	**8,000**	**0**	**16,000**
Research Priority 3a	**SFBDE, CBE, NM**	***Take (Entrainment from Hydrokinetic Projects)***	**Conduct research to determine the impacts of hydrokinetic facilities, especially those using turbines.**	**3**	**NMFS, state and other federal agencies, private companies**	**10**	**0**	**200**	**300**	**0**	**500**
Recovery Action 4a	**SRB, SFBDE**	***Take (Poaching)***	**Reduce poaching in the Sacramento, Feather, and Yuba rivers and when the weirs overtop at the Yolo and Sutter bypasses through increased enforcement presence or improved relocation methods.**	**2**	**CDFW, NMFS, other state and federal agencies**	**20**	**12,500**	**12,500**	**12,500**	**12,500**	**50,000**

Identifier	Area	Threat Addressed	Recovery Action	Priority	Recovery Partners	Duration (Years)	FY1-5	FY6-10	FY11-15	FY16-20	Total Cost (Thousands of Dollars) FY1-FY20
Recovery Action 4b	**CBE, NM**	***Take (Fisheries)***	**Implement measures to reduce fisheries bycatch of green sturgeon in commercial and recreational fisheries and complete Fishery Management and Evaluation Plans for state fisheries encountering sDPS green sturgeon.**	**2**	**NMFS, CDFW, ODFW, WDFW**	**9**	**525**	**375**	**0**	**0**	**900**
Research Priority 4a	**SRB, SFBDE**	***Take (Poaching)***	**Conduct research to estimate the annual level of mortality of sDPS green sturgeon from poaching.**	**2**	**State agencies, NMFS**	**3**	**300**	**0**	**0**	**0**	**300**
Research Priority 4b	**CBE, NM**	***Take (Fisheries)***	**Conduct research to develop an estimate of green sturgeon immediate and post-release mortality and sub-lethal effects from incidental capture in fisheries (e.g., gillnet, hook and line fisheries (CBE); coastal trawl fisheries (NM)).**	**2**	**ODFW and WDFW, federal agencies, academic institutions, NGOs**	**7**	**390**	**390**	**0**	**0**	**780**
Recovery Action 5a	**SRB, SFBDE**	***Contaminants***	**Improve compliance and implementation of Best Management Practices (BMPs) to reduce input of point and non-point source contaminants within the SRB and SFBDE.**	**2**	**Army Corps, USBR, CDWR/water agencies, NMFS, CDFW, CDPR, USFWS, county and city agencies, private landowners**	**10**	**0**	**0**	**0**	**0**	**0**
Research Priority 5a	**SRB, SFBDE, CBE**	***Altered Prey Base, Contaminants***	**Conduct research to identify contaminants and contaminant concentrations in all life stages of green sturgeon and their prey base.**	**2**	**Academic institutions, state and federal agencies**	**10**	**1,500**	**1,500**	**0**	**0**	**3,000**
Research Priority 5b	**SRB, SFBDE, CBE**	***Altered Prey Base, Contaminants***	**Conduct research to determine the toxicity of identified contaminants on green sturgeon (e.g., physiologically) and their prey base.**	**2**	**Academic institutions, state and federal agencies**	**10**	**0**	**1,500**	**1,500**	**0**	**3,000**
Recovery Action 6a	**SRB**	***Altered Water Temperature***	**Forecast changes in temperatures in accessible spawning and rearing habitat in the Sacramento, Feather, and Yuba rivers for the next century. Use available lab-based tolerances and optima from nDPS as well as sDPS field data to assess the viability of spawning and rearing habitat over forecasted temperature change.**	**2**	**NMFS, academic institutions, state and other federal agencies**	**2**	**0**	**250**	**0**	**0**	**250**
Recovery Action 6b	**CBE, NM**	***Altered Water Temperature***	**Forecast temperature changes in CBE and NM habitats and potential response of the sDPS.**	**2**	**State and federal agencies, Army Corps, Bonneville Power Administration, academic institutions**	**2**	**0**	**250**	**0**	**0**	**250**
Research Priority 6a	**All areas**	***Native and Non-native Species***	**Conduct research to determine how native and non-native species compete with green sturgeon for habitat.**	**3**	**Academic institutions, state and federal agencies**	**15**	**0**	**500**	**500**	**500**	**1,500**

Identifier	Area	Threat Addressed	Recovery Action	Priority	Recovery Partners	Duration (Years)	FY1-5	FY6-10	FY11-15	FY16-20	Total Cost (Thousands of Dollars) FY1-FY20
Research Priority 6b	**CBE**	***Barriers to Migration***	**Conduct research to determine the effect of water quality, including anoxic conditions, on habitat use of green sturgeon.**	**3**	**Academic institutions, state and federal agencies, Army Corps**	**10**	**0**	**0**	**300**	**300**	**600**
Research Priority 6c	**All areas**	***Altered Prey Base, Loss of Wetland Function***	**Conduct research to gain a better understanding of the prey base of all life stages of green sturgeon and potential effect of non-native species and climate change.**	**3**	**Academic institutions, state and federal agencies**	**5**	**0**	**550**	**550**	**0**	**1,100**
Recovery Action 7a	**SFBDE, CBE**	***Predation***	**Develop actions to reduce predation on sDPS green sturgeon in areas where high rates of predation occur based on an evaluation of the severity of marine mammal predation on sDPS green sturgeon.**	**3**	**NMFS, USFWS, state and federal agencies, Army Corps in the Columbia River**	**3**	**0**	**250**	**0**	**0**	**250**
Research Priority 7a	**SRB, SFBDE, CBE**	***Predation***	**Conduct research to determine predation by native and non-native species and potential impact on sDPS recovery.**	**3**	**Academic institutions, state and federal agencies**	**3**	**0**	**1,400**	**0**	**0**	**1,400**
Recovery Action 8a	**SRB**	***Altered Sediment***	**Improve compliance and implementation of BMPs to reduce input of non-point source sediment within the upper SRB.**	**3**	**EPA, SWRCB, RWQCB, USDA, RCDs, industry, individuals**	**10**	**0**	**0**	**0**	**0**	**0**
Research Priority 8a	**SRB**	***Water Depth Modification***	**Conduct research to evaluate sDPS spawning substrate suitability in the Sacramento, Feather, and Yuba rivers.**	**2**	**State and federal agencies, academic institutions**	**3**	**300**	**0**	**0**	**0**	**300**
Research Priority 8b	**CBE**	***Altered Turbidity, Altered Sediment***	**Conduct research on the effects of changes in turbidity and sediment load on green sturgeon habitat in the CBEs and consequent effects, if any on individual growth and survival.**	**3**	**State and federal agencies, Army Corps and Bonneville Power Administration in the Columbia River**	**3**	**0**	**300**	**0**	**0**	**300**
Recovery Action 9a	**CBE**	***Contaminants (Oil and Chemical Spill)***	**Assess efficacy of oil and chemical spill response plans in the sDPS range in minimizing potential adverse effects to green sturgeon and develop updated plans as necessary.**	**3**	**EPA, USFWS, CDFW, OR DEQ, WDOE, ADEC, NMFS**	**5**	**0**	**50**	**0**	**0**	**50**
Research Priority 9a	**NM**	***Disease***	**Include condition/health study in long-term green sturgeon monitoring to determine potential risk of disease to the sDPS.**	**3**	**State and federal agencies, academic institutions**	**10**	**0**	**2,500**	**2,500**	**0**	**5,000**
Monitoring Priority 1	**SRB**	***N/A***	**Monitor the annual abundance of sDPS green sturgeon spawning adults in the Sacramento, Feather, and Yuba rivers.**	**2**	**State and federal agencies, academic institutions, private companies**	**20**	**734**	**734**	**734**	**734**	**2,936**
Monitoring Priority 2	**SRB**	***N/A***	**Monitor trends in the annual production of larval sDPS green sturgeon from the Sacramento, Feather, and Yuba rivers.**	**2**	**State and federal agencies, academic institutions, private companies**	**20**	**1,000**	**1,000**	**1,000**	**1,000**	**4,000**

Identifier	Area	Threat Addressed	Recovery Action	Priority	Recovery Partners	Duration (Years)	FY1-5	FY6-10	FY11-15	FY16-20	Total Cost (Thousands of Dollars) FY1-FY20
Monitoring Priority 3	SRB, SFBDE	*N/A*	Monitor trends in the annual production and habitat use of juvenile sDPS green sturgeon in the SRB and SFBDE.	2	State and federal agencies, academic institutions	20	3,500	3,500	3,500	3,500	14,000
Monitoring Priority 4	SRB, SFBDE, CBE	*N/A*	Monitor the population age structure (size classes) of sDPS green sturgeon once every five years.	2	State and federal agencies, academic institutions	20	100	100	100	100	400
Monitoring Priority 5	SRB, SFBDE	*N/A*	Assess genetic diversity of spawning and juvenile sDPS green sturgeon annually, if possible, or for at least three consecutive years each ten-year period. Develop a system to assess effective population size of sDPS spawning adults.	2	State and federal agencies, academic institutions, private companies	20	65	65	65	65	260
Monitoring Priority 6	SFBDE, CBE, NM	*N/A*	Use telemetry to monitor sDPS use of estuaries and coastal environments.	3	State and federal agencies, academic institutions, Army Corps, Bonneville Power Administration (Columbia River)	20	6,000	6,000	6,000	6,000	24,000
Monitoring Priority 7	All areas	*N/A*	Work cooperatively with fisheries that regularly encounter the sDPS to utilize these encounters as a source of monitoring data on recovery.	2	NMFS, state agencies	20	100	100	100	100	400
Monitoring Priority 8	All areas	*N/A*	Implement strategies in state, Federal, and tribal fisheries to monitor and reduce the take of green sturgeon in fisheries.	3	NMFS, state agencies, tribes	20	50	50	50	50	200
Monitoring Priority 9	All areas	*N/A*	Implement long-term monitoring of contaminant levels in adults and compare to inter-annual spawning and recruitment to understand potential relationships between contaminant levels, reproduction, and recruitment.	2	State and federal agencies, academic institutions	15	25	25	25	0	75
Monitoring Priority 10	SRB region	*N/A*	Use eDNA or other methods to monitor unoccupied rivers/non-spawning population rivers for the presence of green sturgeon, particularly during summer months.	2	State and federal agencies, academic institutions, private companies	20	500	500	0	0	1,000
Education & Outreach Priority 1	All areas	*N/A*	Present recovery plan aims, objectives, criteria and actions to interested user groups and management agencies as well as school groups.	3	NMFS, state and federal agencies, NGOs	10	29	15	0	0	44

Identifier	Area	Threat Addressed	Recovery Action	Priority	Recovery Partners	Duration (Years)	FY1-5	FY6-10	FY11-15	FY16-20	Total Cost (Thousands of Dollars) FY1-FY20
Education & Outreach Priority 2	**All areas**	***N/A***	**Develop outreach program for law enforcement personnel, fishing guides, and fishermen on green sturgeon protection under Federal and State laws and the potential problems of post-release mortality and poaching. Distribute the green sturgeon identification flyers coast wide (include in State fishing regulations and websites, and post at boat ramps, fishing sites, and bait shops).**	**2**	**NMFS, state and federal agencies, NGOs**	**5**	**250**	**0**	**0**	**0**	**250**

Literature Cited

55 FR 24296. 1990. Endangered and Threatened Species: Listing and Recovery Priority Guidelines. National Marine Fisheries Service, pp. 24296-24298.

68 FR 4433. 2003. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to List North American Green Sturgeon as a Threatened or Endangered Species. National Marine Fisheries Service, pp. 4433-4441.

71 FR 17757. 2006. Endangered and Threatened Wildlife and Plants: Threatened Status for Southern Distinct Population Segment of North American Green Sturgeon. National Marine Fisheries Service, pp. 17757-17766.

74 FR 52300. 2009. Final Rulemaking to Designate Critical Habitat for the Threatened Southern Distinct Population Segment of North American Green Sturgeon. pp. 52300-52351.

75 FR 30714. 2010. Endangered and Threatened Wildlife and Plants: Final Rulemaking to Establish Take Prohibitions for the Threatened Southern Distinct Population Segment of North American Green Sturgeon. pp. 30714-30730.

81 FR 7414. 2016. Listing Endangered and Threatened Species and Designating Critical Habitat; Implementing Changes to the Regulations for Designating Critical Habitat; Final Rule. pp. 7414-7440.

Adams, P. B., C. Grimes, J. E. Hightower, S. T. Lindley, M. L. Moser, and M. J. Parsley. 2007. Population Status of North American Green Sturgeon, *Acipenser medirostris*. Environmental Biology of Fishes 79(3-4):339-356.

Adams, P. B., C. B. Grimes, J. E. Hightower, S. T. Lindley, and M. L. Moser. 2002. Status Review for North American Green Sturgeon, *Acipenser medirostris*. National Marine Fisheries Service, pp. 58.

Allen, P. J. and J. J. Cech. 2007. Age/Size Effects on Juvenile Green Sturgeon, *Acipenser medirostris*, Oxygen Consumption, Growth, and Osmoregulation in Saline Environments. Environmental Biology of Fishes 79(3-4):211-229.

Allen, P. J., M. McEnroe, T. Forostyan, S. Cole, M. M. Nicholl, B. Hodge, and J. J. Cech, Jr. 2011. Ontogeny of Salinity Tolerance and Evidence for Seawater-Entry Preparation in Juvenile Green Sturgeon, *Acipenser medirostris*. Journal of Comparative Physiology B: Biochemical, Systemic, and Environmental Physiology 181(8):1045-1062.

Allen, P. J., M. Nicholl, S. Cole, A. Vlazny, and J. J. Cech. 2006. Growth of Larval to Juvenile Green Sturgeon in Elevated Temperature Regimes. Transactions of the American Fisheries Society 135(1):89-96.

Anderson, E. C., T. C. Ng, E. D. Crandall, and J. C. Garza. 2017. Genetic and Individual Assignment of Tetraploid Green Sturgeon with SNP Assay Data. Conservation Genetics 18(5):1119-1130.

Anderson, J. J., M. Deas, M. Duffy, D. L. Erickson, R. Reisenbichler, K. A. Rose, and P. E. Smith. 2009. Independent Review of a Draft Version of the 2009 NMFS OCAP Biological Opinion CALFED Science Review Panel. pp. 52.

Ayres, W. O. 1854. Descriptions of Three New Species of Sturgeon San Francisco. Proceedings of the California Academy of Natural Sciences 1:14-15.

Bakke, A. M., D. H. Tashjian, C. F. Wang, S. H. Lee, S. C. Bai, and S. S. O. Hung. 2010. Competition between Selenomethionine and Methionine Absorption in the Intestinal Tract of Green Sturgeon *(Acipenser medirostris)*. Aquatic Toxicology 96:62-69.

Beamesderfer, R., M. Simpson, G. Kopp, J. Inman, A. Fuller, and D. Demko. 2004. Historical and Current Information on Green Sturgeon Occurrence in the Sacramento and San Joaquin Rivers and Tributaries. State Water Contractors and S. P. Cramer & Associates, Inc., Oakdale, California.

Beamesderfer, R. C. P., M. L. Simpson, and G. J. Kopp. 2007. Use of Life History Information in a Population Model for Sacramento Green Sturgeon. Environmental Biology of Fishes 79(3-4):315-337.

Beccio, M. 2018. Yuba River Green Sturgeon. pers. comm. J. Heublein. June 25, 2018.

Benson, R. L., S. Turo, and B. W. McCovey. 2007. Migration and Movement Patterns of Green Sturgeon *(Acipenser medirostris)* in the Klamath and Trinity Rivers, California, USA. Environmental Biology of Fishes 79(3-4):269-279.

Billard, R. and G. Lecointre. 2000. Biology and Conservation of Sturgeon and Paddlefish. Reviews in Fish Biology and Fisheries 10(4):355-392.

Biological Review Team. 2005. Green Sturgeon *(Acipenser medirostris)* Status Review Update. National Marine Fisheries Service, pp. 35.

Birstein, V. J. and W. E. Bemis. 1997. How Many Species Are There within the Genus Acipenser? Environmental Biology of Fishes 48:157-163.

Borin, J. M., M. L. Moser, A. G. Hansen, D. A. Beauchamp, S. C. Corbett, B. R. Dumbauld, C. Pruitt, J. L. Ruesink, and C. Donoghue. 2017. Energetic Requirements of Green Sturgeon *(Acipenser medirostris)* Feeding on Burrowing Shrimp *(Neotrypaea californiensis)* in Estuaries: Importance of Temperature, Reproductive Investment, and Residence Time. Environmental Biology of Fishes 100(12):1561-1573.

Brown, K. 2007. Evidence of Spawning by Green Sturgeon, *Acipenser medirostris*, in the Upper Sacramento River, California. Environmental Biology of Fishes 79(3-4):297-303.

CALFED. 2005. Fish Passage Improvement, an Element of CALFED's Ecosystem Restoration Program. CALFED, pp. 263.

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program Plan Volume II: Ecological Management Zone Visions. CALFED, pp. 427.

California Department of Fish and Game. 1992. Sturgeon in Relation to Water Development in the Sacramento-San Joaquin Estuary. pp. 17.

California Department of Fish and Game. 2002. Comments to NMFS Regarding Green Sturgeon Listing.

California Department of Fish and Wildlife. 2013. GS Status Review Report Comments. pers. comm. P. Doukakis. 12/19/2013.

Carretta, J. V., K. A. Forney, E. Oleson, D. W. Weller, A. R. Lang, J. Baker, M. Muto, B. Hanson, A. J. Orr, H. Huber, M. S. Lowry, J. Barlow, J. E. Moore, D. Lynch, L. Carswell, and R. L. Brownell. 2017. U.S. Pacific Marine Mammal Stock Assessments 2016. U.S. Department of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-577, pp. 414.

Cech, J. J. J., S. I. Doroshov, G. P. Moberg, B. May, R. Schaffter, and D. M. Kohlhorst. 2002. Biological Assessment of Green Sturgeon in the Sacramento-San Joaquin Watershed (Phase 1). Final Report to the CALFED Bay-Delta Program. Project #98-C-15, Contract #B-81738.

Chapman, J. W., B. R. Dumbauld, G. Itani, and J. C. Markham. 2012. An Introduced Asian Parasite Threatens Northeastern Pacific Estuarine Ecosystems. Biological Invasions 14(6):1221-1236.

Colway, C. and D. E. Stevenson. 2007. Confirmed Records of Two Green Sturgeon from the Bering Sea and Gulf of Alaska. Northwestern Naturalist 88:188-192.

Cramer Fish Sciences. 2011. Memo: Green Sturgeon Observations at Daguerre Point Dam, Yuba River, CA. FWS Grant Number: 813329G011.

De Riu, N., J. W. Lee, S. S. Huang, G. Moniello, and S. S. Hung. 2014. Effect of Dietary Selenomethionine on Growth Performance, Tissue Burden, and Histopathology in Green and White Sturgeon. Aquatic Toxicology 148:65-73.

Deng, X., J. P. Van Enennaam, and S. I. Doroshov. 2002. Comparison of Early Life Stages and Growth of Green and White Sturgeon. American Fisheries Society Symposium 28:237-248.

DuBois, J. and A. Danos. 2017. 2016 Sturgeon Fishing Report Card: Preliminary Data Report. California Department of Fish and Wildlife, pp. 16.

DuBois, J. and M. D. Harris. 2015. 2014 Sturgeon Fishing Report Card: Preliminary Data Report. California Department of Fish and Wildlife, pp. 14.

DuBois, J. and M. D. Harris. 2016. 2015 Sturgeon Fishing Report Card: Preliminary Data Report. California Department of Fish and Wildlife, pp. 14.

DuBois, J., M. D. Harris, and J. Mauldin. 2014. 2013 Sturgeon Fishing Report Card: Preliminary Data Report. California Department of Fish and Wildlife, pp. 14.

Dumbauld, B. R., D. L. Holden, and O. P. Langness. 2008. Do Sturgeon Limit Burrowing Shrimp Populations in Pacific Northwest Estuaries? Environmental Biology of Fishes 83(3):283-296.

Durand, J., W. Fleenor, R. McElreath, M. J. Santos, and P. Moyle. 2016. Physical Controls on the Distribution of the Submersed Aquatic Weed *Egeria densa* in the Sacramento-San Joaquin Delta, California and Implications for Habitat Restoration. San Francisco Estuary and Watershed Science 14(1):1-20.

EPRI (Electric Power Research Institute). 2013. EPRI Workshop on EMF and Aquatic Life, Technical Report.

Erickson, D. L. and J. E. Hightower. 2007. Oceanic Distribution and Behavior of Green Sturgeon. American Fisheries Society Symposium 56:197-211.

Erickson, D. L. and M. A. H. Webb. 2007. Spawning Periodicity, Spawning Migration, and Size at Maturity of Green Sturgeon, *Acipenser medirostris*, in the Rogue River, Oregon. Environmental Biology of Fishes 79(3-4):255-268.

Feist, G. W., M. A. Webb, D. T. Gundersen, E. P. Foster, C. B. Schreck, A. G. Maule, and M. S. Fitzpatrick. 2005. Evidence of Detrimental Effects of Environmental Contaminants on Growth and Reproductive Physiology of White Sturgeon in Impounded Areas of the Columbia River. Environmental Health Perspectives 113(12):1675-1682.

Ficklin, D. L., I. T. Stewart, and E. P. Maurer. 2012. Projections of 21st Century Sierra Nevada Local Hydrologic Flow Components Using an Ensemble of General Circulation Models. Journal of the American Water Resources Association 48(6):1104-1125.

Fisheries and Oceans Canada. 2014. Recovery Strategy for White Sturgeon *(Acipenser transmontanus)* in Canada (Final). *In* Species at Risk Act Recovery Strategy Series. Ottawa.

Franklin, I. R. 1980. Evolutionary Change in Small Populations. Pages 135-149 *in* Conservation Biology: An Evolutionary-Ecological Perspective, M. E. Soulé and B. A. Wilcox, editors. Sinauer Associates, Sunderland, MA.

Frew, J. A. 2013. Environmental and Systemic Exposure Assessment for Green Sturgeon Following Application of Imidacloprid for the Control of Burrowing Shrimp in Willapa Bay, Washington. University of Washington.

Frew, J. A., M. Sadilek, and C. E. Grue. 2015. Assessing the Risk to Green Sturgeon from Application of Imidacloprid to Control Burrowing Shrimp in Willapa Bay, Washington-Part I: Exposure Characterization. Environmental Toxicology and Chemistry 34(11):2533-2541.

Ganssle, D. 1966. Fishes and Decapods of San Pablo and Suisun Bays. Ecological Studies of the Sacramento-San Joaquin Estuary, Part I: Zooplankton, Zoobenthos, and Fishes of San Pablo and Suisun Bays, Zooplankton and Zoobenthos of the Delta. Fish Bulletin 133:64-94.

Grosholz, E. D., L. A. Levin, A. C. Tyler, and C. Neira. 2009. Changes in Community Structure and Ecosystem Function Following *Spartina alterniflora* Invasion of Pacific Estuaries. Pages 23-40 *in* Human Impacts on Salt Marshes: A Global Perspective. University of California Press.

Haller, L. Y., S. S. O. Hung, L. S., J. G. Fadel, J. H. Lee, M. McEnroe, and N. A. Fangue. 2015. Effect of Nutritional Status on the Osmoregulation of Green Sturgeon *(Acipenser medirostris)*. Physiological and Biochemical Zoology 88(1):22-42.

Hansel, H. C., J. G. Romine, and R. W. Perry. 2017. Acoustic Tag Detections of Green Sturgeon in the Columbia River and Coos Bay Estuaries, Washington and Oregon, 2010–11. U.S. Geological Survey and U.S. Fish and Wildlife Service, pp. 40.

Heublein, J., B. R., R. D. Chase, P. Doukakis, M. Gingras, D. Hampton, J. A. Israel, Z. J. Jackson, R. C. Johnson, O. P. Langness, S. Luis, E. Mora, M. L. Moser, L. Rohrbach, A. M. Seesholtz, and T. Sommer. 2017b. Improved Fisheries Management through Life Stage Monitoring: The Case for the Southern Distinct Population Segment of North American Green Sturgeon and the Sacramento-San Joaquin River White Sturgeon. National Marine Fisheries Service, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-588, pp. 1-43.

Heublein, J., B. R., R. D. Chase, P. Doukakis, M. Gingras, D. Hampton, J. A. Israel, Z. J. Jackson, R. C. Johnson, O. P. Langness, S. Luis, E. Mora, M. L. Moser, L. Rohrbach, A. M. Seesholtz, T. Sommer, and J. S. Stuart. 2017a. Life History and Current Monitoring Inventory of San Francisco Estuary Sturgeon. National Marine Fisheries Service, NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-589, pp. 1-47.

Heublein, J. C., J. T. Kelly, C. E. Crocker, A. P. Klimley, and S. T. Lindley. 2009. Migration of Green Sturgeon, *Acipenser medirostris*, in the Sacramento River. Environmental Biology of Fishes 84(3):245-258.

Hildebrand, L. R. and M. Parsley. 2013. Upper Columbia White Sturgeon Recovery Plan - 2012 Revision, White Sturgeon Recovery Initiative.

Huff, D. D., S. T. Lindley, P. S. Rankin, and E. A. Mora. 2011. Green Sturgeon Physical Habitat Use in the Coastal Pacific Ocean. PLOS ONE 6(9):e25156.

Huff, D. D., S. T. Lindley, B. K. Wells, and F. Chai. 2012. Green Sturgeon Distribution in the Pacific Ocean Estimated from Modeled Oceanographic Features and Migration Behavior. PLOS One 7(9):e45852.

Israel, J. A., J. F. Cordes, M. A. Blumberg, and B. May. 2004. Geographic Patterns of Genetic Differentiation among Collections of Green Sturgeon. North American Journal of Fisheries Management 24(3):922-931.

Israel, J. A., M. J. Thomas, R. Corwin, A. Hearn, R. D. Chase, and A. P. Klimley. 2010. Implications of Seasonal Migration Impediments in Green Sturgeon on the Sacramento River. Poster presented at 6th Biennial Bay–Delta Science Conference. September 27-29, 2010. Sacramento, CA.

IUCN (International Union for Conservation of Nature). 2001. IUCN Red List Categories and Criteria: Version 3.1, Second Edition. IUCN Council, Gland, Switzerland.

Jackson, Z. J., J. J. Gruber, and J. P. Van Eenennaam. 2016. White Sturgeon Spawning in the San Joaquin River, California, and Effects of Water Management. Journal of Fish and Wildlife Management 7(1):171-180.

Jamieson, G. S., E. D. Grosholz, D. A. Armstrong, and R. W. Elner. 1998. Potential Ecological Implications from the Introduction of the European Green Crab, *Carcinus maenas* (Linneaus), to British Columbia, Canada, and Washington, USA. Journal of Natural History 32(10-11):1587-1598.

Keefer, M. L., R. J. Stansell, S. C. Tackley, W. T. Nagy, K. M. Gibbons, C. A. Peery, and C. C. Caudill. 2012. Use of Radiotelemetry and Direct Observations to Evaluate Sea Lion Predation on Adult Pacific Salmonids at Bonneville Dam. Transactions of the American Fisheries Society 141(5):1236-1251.

Kelly, J. T., A. P. Klimley, and C. E. Crocker. 2007. Movements of Green Sturgeon, *Acipenser medirostris,* in the San Francisco Bay Estuary, California. Environmental Biology of Fishes 79(3-4):1-44.

Klimley, A. P., M. J. Thomas, and A. Hearn. 2015b. Juvenile Green Sturgeon Movements and Identification of Critical Rearing Habitat. U.S. Bureau of Reclamation, pp. 8.

Klimley, A. P., M. T. Wyman, and R. Kavet. 2017. Chinook Salmon and Green Sturgeon Migrate through San Francisco Estuary Despite Large Distortions in the Local Magnetic Field Produced by Bridges. PLOS ONE 12(6):16.

Klimley, P. A., E. D. Chapman, J. J. Cech, D. E. Cocherell, N. A. Fangue, M. Gingras, Z. Jackson, E. A. Miller, E. A. Mora, J. B. Poletto, A. M. Schreier, A. Seesholtz, K. J. Sulak, M. J. Thomas, D. Woodbury, and M. T. Wyman. 2015a. Sturgeon in the Sacramento-San Joaquin Watershed: New Insights to Support Conservation and Management. San Francisco Estuary and Watershed Science 13(4):1-19.

Knowles, N. and D. R. Cayan. 2002. Potential Effects of Global Warming on the Sacramento/San Joaquin Watershed and the San Francisco Estuary. Geophysical Research Letters 29(18):1891-1895.

Kogut, N. J. 2008. Overbite Claims, *Corbula amurensis* Defecated Alive by White Sturgeon, *Acipenser transmontanus*. California Department of Fish and Game 94:143-149.

Kurth, R. 2018. Personal Communication with Joe Heublein (NMFS Biologist) and Others Regarding Detections of Green Sturgeon in the Yuba River. pers. comm. L. Krasnow and P. Doukakis. April 26, 2018.

Kynard, B., E. Parker, and T. Parker. 2005. Behavior of Early Life Intervals of Klamath River Green Sturgeon, *Acipenser medirostris*, with a Note on Body Color. Environmental Biology of Fishes 72(1):85-97.

Langness, O. P. 2005. Green Sturgeon Utilization of the Coastal Estuaries of Washington State. Department of Fish and Wildlife, pp. 42.

Langness, O. P. 2007. Risk Assessment of Green Sturgeon in Washington. Standard Final Performance Report (Corrected) of Washington Department of Fish and Wildlife to U.S. Fish and Wildlife Service, Portland, Oregon. Doi Grant T-1-4. Performance Period 9/19/2002 through 9/30/2006.

Lee, J., N. De Riu, L. Seunghyung, S. C. Bai, G. Moniello, and S. O. Hung. 2011. Effects of Dietary Methylmercury on Growth Performance and Tissue Burden in Juvenile Green *(Acipenser medirostris)* and White Sturgeon *(A. transmontanus)*. Aquatic Toxicology 105:227-234.

Linares-Casenave, J., I. Werner, J. P. Van Eenennaam, and S. I. Doroshov. 2013. Temperature Stress Induces Notochord Abnormalities and Heat Shock Proteins Expression in Larval Green Sturgeon *(Acipenser medirostris* Ayres 1854). Journal of Applied Ichthyology 29(5):958-967.

Lindley, S. T., D. L. Erickson, M. L. Moser, G. Williams, O. P. Langness, B. W. McCovey, M. Belchik, D. Vogel, W. Pinnix, J. T. Kelly, J. C. Heublein, and A. P. Klimley. 2011. Electronic Tagging of Green Sturgeon Reveals Population Structure and Movement among Estuaries. Transactions of the American Fisheries Society 140(1):108-122.

Lindley, S. T., M. L. Moser, D. L. Erickson, M. Belchik, D. W. Welch, E. L. Rechisky, J. T. Kelly, J. Heublein, and A. P. Klimley. 2008. Marine Migration of North American Green Sturgeon. Transactions of the American Fisheries Society 137(1):182-194.

Linville, R. G., S. N. Luoma, L. Cutter, and G. A. Cutter. 2002. Increased Selenium Threat as a Result of Invasion of the Exotic Bivalve *Potamocorbula amurensis* into the San Francisco Bay-Delta. Aquatic Toxicology 57(1-2):51-64.

Lockington, W. N. 1879. Report of the Commissioners of Fisheries of the State of California for the Years of 1878-1879.

Lower Yuba River Accord River Management Team Planning Group. 2010. Lower Yuba River Water Temperature Objectives Technical Memorandum. pp. 75.

Martarano, S. 2018. Confirmed in Stanislaus River for the First Time, a Green Sturgeon Highlights Benefits of Longtime Research and Restoration Efforts. https://www.fws.gov/cno/newsroom/highlights/2018/green_sturgeon/. 03/01/2018.

Mayfield, R. B. and J. J. Cech. 2004. Temperature Effects on Green Sturgeon Bioenergetics. Transactions of the American Fisheries Society 133(4):961-970.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-42, pp. 174.

Mora, E. 2016. A Confluence of Sturgeon Migration: Adult Abundance and Juvenile Survival. Ph.D. Dissertation. University of California, Davis.

Mora, E. A., R. D. Battleson, S. T. Lindley, M. J. Thomas, R. Bellmer, L. J. Zarri, and A. P. Klimley. 2018. Estimating the Annual Spawning Run Size and Population Size of the Southern Distinct Population Segment of Green Sturgeon. Transactions of the American Fisheries Society 147(1):195-203.

Mora, E. A., S. T. Lindley, D. L. Erickson, and A. P. Klimley. 2009. Do Impassable Dams and Flow Regulation Constrain the Distribution of Green Sturgeon in the Sacramento River, California? Journal of Applied Ichthyology 25:39-47.

Moser, M. L., J. A. Israel, M. Neuman, S. T. Lindley, D. L. Erickson, B. W. McCovey Jr., and A. P. Klimley. 2016. Biology and Life History of Green Sturgeon (*Acipenser medirostris* Ayres, 1854): State of the Science. Journal of Applied Ichthyology 32(Suppl. 1):67-86.

Moser, M. L. and S. T. Lindley. 2007. Use of Washington Estuaries by Subadult and Adult Green Sturgeon. Environmental Biology of Fishes 79(3-4):243-253.

Moser, M. L., K. Patten, S. C. Corbett, B. E. Feist, and S. T. Lindley. 2017. Abundance and Distribution of Sturgeon Feeding Pits in a Washington Estuary. Environmental Biology of Fishes 100(5):597-609.

Moyle, P. B. 2002. Inland Fishes of California. University of California Press, Berkeley and Los Angeles.

Moyle, P. B., R. M. Yoshiyama, J. E. Williams, and E. D. Wikramanayake. 1995. Fish Species of Special Concern in California. California Department of Fish and Game, pp.

Mussen, T. D., D. Cocherell, J. B. Poletto, J. S. Reardon, Z. Hockett, A. Ercan, H. Bandeh, M. L. Kavvas, J. J. Cech, Jr., and N. A. Fangue. 2014. Unscreened Water-Diversion Pipes Pose an Entrainment Risk to the Threatened Green Sturgeon, *Acipenser medirostris*. PLOS One 9(1):e86321.

Muto, M., V. T. Helker, R. P. Angliss, B. A. Allen, P. L. Boveng, J. M. Breiwick, M. F. Cameron, P. J. Clapham, S. P. Dahle, M. E. Dahlheim, B. S. Fadely, M. C. Ferguson, L. W. Fritz, R. C. Hobbs, Y. V. Ivashchenko, A. S. Kennedy, J. M. London, S. A. Mizroch, R. R. Ream, E. L. Richmond, K. E. W. Shelden, R. G. Towell, P. R. Wade, J. M. Waite, and A. N. Zerbini. 2017. Alaska Marine Mammal Stock Assessments, 2016. National Marine Fisheries Service, NOAA Technical Memorandum NMFS-AFSC-355, pp. 1-375.

Nakamoto, R. J., T. T. Kisanuki, and G. H. Goldsmith. 1995. Age and Growth of Klamath River Green Sturgeon *(Acipenser medirostris)*. U.S. Forest Service and U.S. Fish and Wildlife Service, pp. 18.

National Marine Fisheries Service. 2009a. NMFS Biological and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. pp. 844.

National Marine Fisheries Service. 2009b. Biological Opinion on Nationwide Permit 48 Washington. U.S. Fish and Wildlife Service, pp. 198.

National Marine Fisheries Service. 2009c. Final Biological Report. Designation of Critical Habitat for the Threatened Southern Distinct Population Segment of North American Green Sturgeon. U.S. Department of Commerce, pp. 144.

National Marine Fisheries Service. 2014. Final Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-Run Chinook Salmon and Central Valley Spring-Run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead. pp. 1-427.

National Marine Fisheries Service. 2015. 5-Year Summary and Evaluation: Southern Distinct Population Segment of the North American Green Sturgeon. U.S. Department of Commerce, pp. 42.

National Marine Fisheries Service. 2016. Biological Opinion on Oroville Facilities Hydroelectric Project Relicensing. pp. 439.

National Marine Fisheries Service. 2017. Biological Opinion on the Environmental Protection Agency's Registration of Pesticides Containing Chlorpyrifos, Diazinon, and Malathion. pp. 3749.

Nelson, P. A., D. Behrens, J. Castle, G. Crawford, R. N. Gaddam, S. C. Hackett, D. Largier, P. Lohse, K. L. Mills, P. T. Raimondi, M. Robart, W. J. Sydeman, S. A. Thompson, and S. Woo. 2008. Developing Wave Energy in Coastal California: Potential Socio-Economic and Environmental Effects. California Energy Commission, pp. 182.

Nguyen, R. M. and C. E. Crocker. 2007. The Effects of Substrate Composition on Foraging Behavior and Growth Rate of Larval Green Sturgeon, *Acipenser medirostris*. Environmental Biology of Fishes 76(2-4):129-138.

Niggemyer, A. and T. Duster. 2003. Final Assessment of Potential Sturgeon Passage Impediments, SP-F3.2 Task 3A. California Department of Water Resources, pp. 27.

Normandeau, E., T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranches and Other Marine Species. U. S. Department of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Bedford, NH.

North, J. A., R. A. Farr, and P. Vescei. 2002. A Comparison of Meristic and Morphometric Characters of Green Sturgeon *Acipenser medirostris*. Journal of Applied Ichthyology 18(4-6):234-239.

Oregon Department of Fish and Wildlife. 2017. Comments Submitted to NMFS Regarding Draft Recovery Plan for the Southern DPS of Green Sturgeon. Oregon Department of Fish and Wildlife, pp. 2.

Patten, K. 2014. The Impacts of Nonnative Japanese Eelgrass *(Zostera japonica)* on Commercial Shellfish Production in Willapa Bay, WA. Agricultural Sciences 5(7):625-633.

Poletto, J. B., D. E. Cocherell, N. Ho, J. J. Cech, A. P. Klimley, and N. A. Fangue. 2014a. Juvenile Green Sturgeon *(Acipenser medirostris)* and White Sturgeon *(Acipenser transmontanus)* Behavior near Water-Diversion Fish Screens: Experiments in a Laboratory Swimming Flume. Canadian Journal of Fisheries and Aquatic Sciences 71(7):1030-1038.

Poletto, J. B., D. E. Cocherell, T. D. Mussen, A. Ercan, H. Bandeh, M. L. Kavvas, J. J. Cech, and N. A. Fangue. 2014b. Efficacy of a Sensory Deterrent and Pipe Modifications in Decreasing Entrainment of Juvenile Green Sturgeon *(Acipenser medirostris)* at Unscreened Water Diversions. Conservation Physiology 2(1):1-2.

Poytress, W. R., J. J. Gruber, and J. P. Van Eenennaam. 2011. 2010 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys U.S. Fish and Wildlife Service and University of California Davis, pp. 1-48.

Poytress, W. R., J. J. Gruber, and J. P. Van Eenennaam. 2012. 2011 Upper Sacramento River Green Sturgeon Spawning Habitat and Larval Migration Surveys U.S. Fish and Wildlife Service and University of California Davis, pp. 1-46.

Poytress, W. R., J. J. Gruber, J. P. Van Eenennaam, and M. Gard. 2015. Spatial and Temporal Distribution of Spawning Events and Habitat Characteristics of Sacramento River Green Sturgeon. Transactions of the American Fisheries Society 144(6):1129-1142.

Radtke, L. D. 1966. Distribution of Smelt, Juvenile Sturgeon, and Starry Flounder in the Sacramento-San Joaquin Delta with Observations on Food of Sturgeon. California Department of Fish and Game, pp. 115-119.

Rosales-Cassian, J. R. and C. Almeda-Juaregui. 2009. Unusual Occurrence of a Green Sturgeon (*Acipenser medirostris)* at El Socorro Bay, Baja California, Mexico California Cooperative Fisheries Investigations. CalCOFI Reports 50:169-171.

Sardella, B. A. and D. Kultz. 2014. The Physiological Responses of Green Sturgeon *(Acipenser medirostris)* to Potential Global Climate Change Stressors. Physiological and Biochemical Zoology 87(3):456-463.

Schaffter, R. 1997. White Sturgeon Spawning Migrations and Location of Spawning Habitat in the Sacramento River, California. California Department of Fish and Game, pp. 1-20.

Schreier, A., O. P. Langness, J. A. Israel, and E. Van Dyke. 2016. Further Investigation of Green Sturgeon *(Acipenser medirostris)* Distinct Population Segment Composition in Non-Natal Estuaries and Preliminary Evidence of Columbia River Spawning. Environmental Biology of Fishes 99(12):1021-1032.

Seesholtz, A. M., M. J. Manuel, and J. P. Van Eenennaam. 2014. First Documented Spawning and Associated Habitat Conditions for Green Sturgeon in the Feather River, California. Environmental Biology of Fishes 98(3):905-912.

Silvestre, F., J. Linares-Casenave, S. I. Doroshov, and D. Kultz. 2010. A Proteomic Analysis of Green and White Sturgeon Larvae Exposed to Heat Stress and Selenium. Science of the Total Environment 408(16):3176-3188.

Soulé, M. E. 1980. Thresholds for Survival: Maintaining Fitness and Evolutionary Potential. Pages 151-170 *in* Conservation Biology: An Evolutionary-Ecological Perspective, W. E. Soulé and B. A. Wilcox, editors. Sinauer Associates, Sunderland, MA.

State Water Resources Control Board and California Environmental Protection Agency. 2016. Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations. State Water Resources Control Board and California Environmental Protection Agency, pp. 388.

Steel, A. E., M. J. Thomas, and A. P. Klimley. 2018. Reach Specific Use of Spawning Habitat by Adult Green Sturgeon *(Acipenser medirostris)* under Different Operation Schedules at Red Bluff Diversion Dam. Journal of Applied Ichthyology 00:1-8.

Stillwater Sciences and Wiyot Tribe Natural Resources. 2017. Status, Distribution, and Population of Origin of Green Sturgeon in the Eel River: Results of 2014–2016 Studies. Silver Springs, Maryland.

Thomas, M. J., M. L. Peterson, N. Friedenberg, J. P. Van Eenennaam, J. R. Johnson, J. J. Hoover, and A. P. Klimley. 2013. Stranding of Spawning Run Green Sturgeon in the Sacramento River: Post-Rescue Movements and Potential Population-Level Effects. North American Journal of Fisheries Management 33(2):287-297.

U.S. Bureau of Reclamation and California Department of Water Resources. 2012. Yolo Bypass Salmonid Habitat Restoration and Fish Passage Implementation Plan, Long-Term Operation of the Central Valley Project and State Water Project Biological Opinion.

U.S. Fish and Wildlife Service. 1995. Working Paper on Restoration Needs Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. U.S. Fish and Wildlife Service, pp. 544.

Van Eenennaam, J. P., J. Linares, S. I. Doroshov, D. C. Hillemeier, T. E. Willson, and A. A. Nova. 2006. Reproductive Conditions of the Klamath River Green Sturgeon. Transactions of the American Fisheries Society 135(1):151-163.

Van Eenennaam, J. P., J. Linares-Casenave, X. Deng, and S. I. Doroshov. 2005. Effect of Incubation Temperature on Green Sturgeon Embryos, *Acipenser medirostris*. Environmental Biology of Fishes 72:145-154.

Van Eenennaam, J. P., M. A. H. Webb, X. Deng, and S. I. Doroshov. 2001. Artificial Spawning and Larval Rearing of Klamath River Green Sturgeon. Transactions of the American Fisheries Society 130:159-165.

Van Lienden, B., A. Munevar, and T. Das. 2014. West-Wide Climate Risk Assessment Sacramento and San Joaquin Basins Climate Impact Assessment. U.S. Bureau of Reclamation, pp. 1-66.

Vaz, P. G., E. Kebreab, S. S. Hung, J. G. Fadel, S. Lee, and N. A. Fangue. 2015. Impact of Nutrition and Salinity Changes on Biological Performances of Green and White Sturgeon. PLOS ONE 10(4):e0122029.

Waples, R., D. J. Teel, J. M. Myers, and A. R. Marshall. 2004. Life-History Divergence in Chinook Salmon: Historic Contingency and Parallel Evolution. Publications Agencies and Staff of the U.S. Department of Commerce, Paper 454, pp. 386-403.

Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. 2012. Submission to Response to Federal Register. Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife, pp. 64959-64960.

Washington State Department of Ecology. 2012. Preparing for a Changing Climate Washington State's Integrated Climate Response Strategy. Department of Ecology, pp. 207.

Webb, M. A. H. and D. L. Erickson. 2007. Reproductive Structure of the Adult Green Sturgeon, *Acipenser medirostris*, Population in the Rogue River, Oregon. Environmental Biology of Fishes 79(3-4):305-314.

Werner, I., J. Linares-Casenave, J. P. Van Eenennaam, and S. I. Doroshov. 2006. The Effect of Temperature Stress on Development and Heat-Shock Protein Expression in Larval Green Sturgeon *(Acipenser medirostris)*. Environmental Biology of Fishes 79(3-4):191-200.

Wyman, M. T., M. J. Thomas, R. R. McDonald, A. R. Hearn, R. D. Battleson, E. D. Chapman, P. Kinzel, J. T. Minear, E. A. Mora, J. M. Nelson, M. D. Pagel, and A. P. Klimley. 2018. Fine-Scale Habitat Selection of Green Sturgeon *(Acipenser medirostris*) within Three Spawning Locations in the Sacramento River, California. Canadian Journal of Fisheries and Aquatic Sciences 75(5):779-791.

Yuba County Water Agency. 2018. Yuba County Water Agency Comments on National Marine Fisheries Service Draft Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon. Yuba County Water Agency, pp. 18.