Central Valley Landscape Conservation Project

Climate Change Vulnerability Assessment (January 2017 version)

Green Sturgeon

Vulnerability Assessment Summary

Overall Vulnerability Score and Components:

Vulnerability Component	Score
Sensitivity	Moderate-high
Exposure	High
Adaptive Capacity	Moderate
Vulnerability	**Moderate-high**

Overall vulnerability of green sturgeon was scored as moderate-high. The score is the result of moderate-high sensitivity, high future exposure, and moderate adaptive capacity scores.

Key climate factors for the green sturgeon include water temperature, timing of snowmelt and runoff, altered streamflow regimes, and drought. Water temperature regulates spawning and larval development and survival. Runoff timing and altered streamflow regimes also influence spawning timing and estuarine conditions, impacting recruitment and foraging. Drought can exacerbate warm stream temperatures and low flow conditions.

Key non-climate factors for green sturgeon include dams and water diversions, poaching, pollution and poisons, agricultural practices, and nutrient loading. Dams, water diversions, and water management activities can impede spawning and access to cold-water refugia, alter thermal and hydrological regimes, and/or lead to sturgeon mortality. Agricultural practices and pollutions and poisons both lead to reduced sturgeon survival and/or fitness by modifying water and habitat quality, while poaching increases mortality. Nutrient loading can decrease dissolved oxygen levels, impairing larval development.

Flooding is the key disturbance mechanism affecting green sturgeon. Flooding can enhance habitat connectivity by increasing floodplain habitat, but can also increase sedimentation of spawning and adult holding sites. Green sturgeon display a mid-range reproductive strategy; they take a long time to reach reproductive maturity (16-20 years for females; 10-14 years for males), but can lay many eggs (>54,000) depending on female size. Green sturgeon are habitat specialists and prey generalists; they require cool, deep pools with small/medium-sized substrate for spawning, as well as deep river pools and healthy estuarine and ocean conditions for adult life stages.

Green sturgeon are a highly mobile and migratory species, but the southern distinct population segment is listed as a threatened species under the U.S. Endangered Species Act due to habitat loss. Dams and water diversions reduce habitat connectivity and access to historical spawning areas. Green sturgeon in the Sacramento River tend to congregate in only a few pools every year, enhancing the likelihood of large population losses if exposed to poaching or extreme events.

This species has moderate-high intraspecific species diversity; in particular, green sturgeon display high behavioral and life history diversity in terms of spawning, holding, and migration behavior. Although this species is not very resistant to habitat loss and degradation as a result of human activities, adult and juvenile stages appear to be fairly resilient to shifting environmental conditions (e.g., temperature, dissolved oxygen, salinity); egg and larval stages are more vulnerable to these factors.

Management potential for green sturgeon was scored as low-moderate. Management options include regulatory support from the Endangered Species Act and the alteration of dam and water management activities to minimize negative hydrological and thermal impacts on green sturgeon spawning and rearing.

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Introduction

Description of Priority Natural Resource

Green sturgeon (*Acipenser medirostris)* is an anadromous fish found in coastal watersheds along the Pacific Coast of North America. The southern distinct population segment of green sturgeon breeds only in the Sacramento River and is listed as threatened under the U.S. Endangered Species Act (National Marine Fisheries Service [NMFS] 2006).

As part of the Central Valley Landscape Conservation Project, workshop participants identified Green Sturgeon as a Priority Natural Resource for the Central Valley Landscape Conservation Project in a process that involved two steps: 1) gathering information about the species' management importance as indicated by its appearance in existing conservation plans and lists, and 2) a workshop with stakeholders to create the final list of Priority Natural Resources, which includes habitats, species groups, and species. The rationale for choosing the Green Sturgeon as a Priority Natural Resource included the following: the species has high management importance, the species' conservation needs are not entirely represented within a single priority habitat or species group, and because the species is an indicator of benthic food web health, water quality, and ecosystem health in places where salmonids are not present. Please see Appendix A: "Priority Natural Resource Selection Methodology" for more information.

Vulnerability Assessment Methodology

During a two-day workshop in October of 2015, 30 experts representing 16 Central Valley resource management organizations assessed the vulnerability of priority natural resources to changes in climate and non-climate factors, and identified the likely resulting pressures, stresses, and benefits (see Appendix B: "Glossary" for terms used in this report). The expert opinions provided by these participants are referenced throughout this document with an endnote indicating its source[1]. To the extent possible, scientific literature was sought out to support expert opinion garnered at the workshop. Literature searches were conducted for factors and resulting pressures that were rated as high or moderate-high, and all pressures, stresses, and benefits identified in the workshop are included in this report. For more information about the vulnerability assessment methodology, please see Appendix C: "Vulnerability Assessment Methods and Application." Projections of climate and non-climate change for the region were researched and are summarized in Appendix D: "Overview of Projected Future Changes in the California Central Valley".

Vulnerability Assessment Details

Climate Factors

Workshop participants scored the resource's sensitivity to climate factors and this score was used to calculate overall sensitivity. Future exposure to climate factors was scored and the overall exposure score used to calculate climate change vulnerability.

Climate Factor	Sensitivity	Future Exposure
Water temperature	High	High
Timing of snowmelt/runoff	High	High
Streamflow	Moderate-high	High
Drought	Moderate-high	-
Extreme events: storms	Moderate	-
Snowpack amount	-	High
Overall Scores	**Moderate-high**	**High**

Water temperature

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (high confidence)*
> ***Potential refugia:*** *Cold water refugia above rim dams (e.g., Shasta and Keswick Dam on the Sacramento River); conservation hatcheries.*

Water temperature, along with streamflow, influences green sturgeon spawning timing (Heublein et al. 2009; Poytress et al. 2011), with spawning activity in the Sacramento River documented at water temperatures ranging from 10.1-17.6°C (Poytress et al. 2010, 2011, 2012). Increased water temperatures could negatively affect green sturgeon larval survival and fitness; growth deformities have been documented at water temperatures at and above 17°C, hatching success decreases at temperatures above 20°C, and larval mortality has been documented at 23 to >26°C (Van Eenennaam et al. 2005; Linares-Casenave et al. 2013). Larval deformities as a result of high water temperature can increase risk of subsequent mortality by impairing swimming ability (Linares-Casenave et al. 2013). Cold water releases from reservoirs during the summer may help mitigate water temperature increases (Israel & Klimley 2008), although these releases can be in conflict with human water use needs and/or impossible during drought periods (NMFS 2015). In addition, cold water releases (<11°C) for winter-rearing

Chinook salmon (*Oncorhynchus tshawytscha*) from April-June may impede sturgeon larval development (Van Eenennaam et al. 2005). Juveniles and adults appear more resilient to warmer water temperatures (Mayfield & Cech Jr 2004; Allen et al. 2006), and in the marine and coastal environment, adults and subadults appear to occupy a variety of thermal habitats (NMFS 2015).

Timing of snowmelt & runoff

> ***Sensitivity:*** *High (high confidence)*
> ***Future exposure:*** *High (high confidence)*
> ***Potential refugia:*** *Cold water refugia above rim dams (e.g., Shasta and Keswick Dam on the Sacramento River); conservation hatcheries.*

Steamflow

> ***Sensitivity:*** *Moderate-high (high confidence)*
> ***Future exposure:*** *High (high confidence)*
> ***Potential refugia:*** *Cold water refugia above rim dams (e.g., Shasta and Keswick Dam on the Sacramento River); conservation hatcheries.*

Adult green sturgeon typically migrate upstream to spawn from March-April during spring flows initiated by snowmelt and rain, spawn from May-July, hold in deep pools during the summer, and outmigrate in the fall and winter with precipitation-driven increases in flow level (Heublein et al. 2009). Studies of white sturgeon (*Acipenser transmontanus*) indicate that higher flows typically correlate with higher reproductive output (Kohlhorst et al. 1991), and patterns are likely similar for green sturgeon (Israel & Klimley 2008).

Shifts in steamflow timing and volume as a result of reduced snowpack, earlier snowmelt timing, and/or precipitation changes may affect sturgeon migration and recruitment (Heublein et al. 2009; Poytress et al. 2011), as well as estuarine habitat and foraging conditions in San Francisco Bay (Knowles & Cayan 2002). Knowles and Cayan (2002) project a 20% reduction in annual flow in the Sacramento-San Joaquin watershed by 2090, with significant flow changes starting near 2060 and flow reductions being most severe in the northern portion of the watershed. Projected increases in winter runoff and reductions in spring flows will likely interact with reservoir and flood control management and agricultural and urban water demands to affect the timing and volume of peak flows and overall water temperature (CH2M HILL 2014; NMFS 2015), which may affect sturgeon breeding timing and success (NMFS 2015). However, breeding rivers in the study area (primarily the Sacramento and Feather Rivers) are dam-controlled, providing the opportunity to manage flows to support sturgeon spawning (Israel & Klimley 2008).

Drought

> ***Sensitivity:*** *Moderate-high (high confidence)*

Compared to the preceding century (1896-1994), drought years in California have occurred twice as often in the last 20 years (1995-2014; Diffenbaugh et al. 2015). Additionally, the recent drought (2012-2014) has been the most severe drought on record in the Central Valley (Williams et al. 2015).

Drought contributes to low flow conditions and associated high water temperatures, which can reduce sturgeon recruitment and survival (Van Eenennaam et al. 2005; NMFS 2015). Recent drought conditions in 2014-2015 increased water temperatures throughout the green sturgeon's spawning range on the Sacramento River (NMFS 2015). Similarly, low rainfall years have been shown to shorten the sturgeon breeding season in the Klamath River due to elevated water temperatures (Van Eenennaam et al. 2005). However, green sturgeon are long-lived and repeated spawners (Van Eenennaam et al. 2005; Brown 2006; Poytress et al. 2011), so they can wait out a long drought[1].

Storms

Sensitivity: *Moderate-high (moderate confidence)*

Snowpack amount

Future exposure: *High (high confidence)*
Potential refugia: *Cold water refugia above rim dams (e.g., Shasta and Keswick Dam on the Sacramento River); conservation hatcheries.*

Other Factors: Ocean and estuary conditions

In addition to affecting riverine green sturgeon habitat, climate change will likely alter oceanic and nearshore habitat conditions (NMFS 2015). For example, ocean acidification and a projected salinity increase of 33% in the San Francisco Bay Delta as a result of shifting freshwater inputs (CH2M HILL 2014) are likely to affect prey availability and reduce the fitness of sub-adult and non-spawning adult sturgeon in estuarine and marine environments (Sardella & Kültz 2014; Haller et al. 2015; NMFS 2015; Vaz et al. 2015). Similarly, shifts in ocean currents and temperatures could affect green sturgeon due to adult and sub-adult utilization of ocean habitats for feeding and migration. Predicting exact impacts is difficult because green sturgeon currently occupy numerous marine environments with a wide range of salinities, temperatures, and dissolved oxygen levels (NMFS 2015).
Workshop participants did not further discuss the following factors beyond assigning scores.

Climatic changes that may benefit the species:

- Storms may create more habitat, moderate temperatures, and provide attraction flows.
- High snowpack levels may encourage longer occupancy periods

Non-Climate Factors

Workshop participants scored the resource's sensitivity and current exposure to non-climate factors, and these scores were then used to assess their impact on climate change sensitivity.

Non-Climate Factor	Sensitivity	Current Exposure
Agriculture & rangeland practices	Moderate-high	High
Dams, levees, & water diversions	High	High
Nutrient loading	Moderate-high	High
Pollution & poisons	Moderate-high	High
Other factors: Poaching	High	High
Overall Scores	**High**	**High**

Agricultural & rangeland practices

Sensitivity: *Moderate-high (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape.*

Green sturgeon are vulnerable to entrainment or impingement in agricultural water diversions (Israel & Klimley 2008; NMFS 2015). Pesticides and herbicides used in Central Valley agricultural practices (e.g., carbaryl) may affect sturgeon, but impacts have not been studied (NMFS 2015). Upland land uses can also contribute to stream sedimentation, reducing spawning and adult holding sites (Moyle et al. 1992). Agricultural and rangeland practices predominately affect early green sturgeon life history stages (i.e., embryo-2 years) [1].

Dams, levees, & water diversions

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape.*

Dams and water diversions can impede green sturgeon spawning migrations, restrict access to cold-water refugia and breeding habitat, and alter thermal and hydrological regimes (Mora et al. 2009; NMFS 2015). Several dams on the Sacramento River and the tributary Yuba and Feather Rivers have been identified as barriers to sturgeon passage. For example, the Keswick Dam and Oroville Dam are considered impassable, and several other dams allow only limited passage (NMFS 2015). Modeling by Mora et al. (2009) indicates that dams likely inhibit utilization of historical upstream spawning habitat on the Yuba, Pit, McCloud, Little Shasta, and lower Feather Rivers, as well as potential spawning habitat on the San Joaquin and American Rivers, although there is no evidence of these tributaries being used historically. Recently, the

Red Bluff Diversion Dam on the Sacramento River was removed, and sturgeon have increased use of upstream habitat in response (NMFS 2015).

Water management activities including flood control, water storage, and water diversion also influence sturgeon populations. For example, sturgeon can be stranded in flood diversion areas when flood bypass systems are used to moderate high flows (Thomas et al. 2013a). Sturgeon can also be stranded in pools and below weirs[1]. In general, flow regulation activities may have variable impacts on hydrographs, including moderating peak winter flows and exacerbating summer low flows, or alter thermal regimes (warmer winter temperatures, colder summer temperatures; Mora et al. 2009). For example, water management activities may interact with drought conditions to further reduce streamflows and increase water temperatures, potentially affecting sturgeon recruitment and survival (NMFS 2015). Timing of water management activities also influences impacts; for example, prior to removal, the Red Bluff Diversion Dam blocked upstream migration of late-returning green sturgeon when gates were closed in mid-May (Heublein et al. 2009). Additionally, water diversions for agricultural or urban use can entrain sturgeon juveniles and larvae, and there are thousands of diversions along the Sacramento River (Mussen et al. 2014). Most large diversions (>250 cfs) are screened, but many smaller diversions are not (Vogel 2013), and the effectiveness of screens in preventing sturgeon entrainment and impingement are not clear, since screens were primarily designed to protect salmon (NMFS 2015).

Nutrient loading

> ***Sensitivity:*** *Moderate-high (high confidence)*
> ***Current exposure:*** *High (high confidence)*
> ***Pattern of exposure:*** *Consistent across the landscape.*

Nutrient loading from agricultural and urban runoff can increase algal growth and decrease dissolved oxygen levels, particularly in concert with higher water temperature (State of Oregon Department of Environmental Quality 2012). Low dissolved oxygen levels may impair larval sturgeon development and survival (Van Eenennaam et al. 2005), and green sturgeon are believed to have higher oxygen consumption rates than other sturgeon species (Mayfield & Cech Jr 2004).

Pollution & poisons

> ***Sensitivity:*** *Moderate-high (high confidence)*
> ***Current exposure:*** *High (high confidence)*
> ***Pattern of exposure:*** *Consistent across the landscape.*

Green sturgeon – especially young life history stages (i.e., embryo-2 years) – are sensitive to a variety of aquatic contaminants, including selenium and mercury encountered in the sediment of estuarine environments (Linville 2006; Israel & Klimley 2008). These contaminants contribute to altered sturgeon growth and fecundity, reduced egg counts, and larval mortality and growth deformities (Linville 2006). Green sturgeon may also be vulnerable to pesticides and other chemicals, but no extensive studies have been completed to date (NMFS 2015).

Other factors: Poaching

> ***Sensitivity:*** *High (high confidence)*
> ***Current exposure:*** *High (high confidence)*

Green sturgeon are protected from commercial and recreational fishing throughout western North America, but are vulnerable to poaching, particularly since they are sympatric species with white sturgeon, a highly valued "trophy" fish (NMFS 2006). Annual mortality rates due to poaching are unknown (NMFS 2015), but there are documented green sturgeon poaching cases (NMFS 2015).

Disturbance Regimes

Workshop participants scored the resource's sensitivity to disturbance regimes, and these scores were used to calculate climate change sensitivity.

> ***Overall sensitivity to disturbance regimes:*** *Moderate (moderate confidence)*

Disease

Disease impacts on this species are unknown (NMFS 2015).

Flooding

Flooding may create temporary floodplain habitat for juvenile green sturgeon prior to outmigration and/or enhance connectivity with mainstem portions of the river (Israel & Klimley 2008). Flooding may also increase sedimentation, decreasing breeding site and holding area suitability (Moyle et al. 1992).

Life history and reproductive strategy

Workshop participants scored the resource's life history and reproductive strategy, and these scores were used calculate climate change sensitivity.

> ***Species reproductive strategy, representing generation length and number of offspring****: Mid-range reproductive strategy (high confidence)*
> ***Average length of time to reproductive maturity:*** *10-15 years (males); 16-20 years (females)*

Green sturgeon are long-lived species, and individuals do not reach sexual maturity for more than a decade (Van Eenennaam et al. 2006). Females do not reach sexual maturity until 16-20 years of age, and males begin reproducing slightly earlier (Van Eenennaam et al. 2006). Most green sturgeon spawn every 3-4 years, although some spawn more or less frequently (range of 2-6 years; Brown 2006; Poytress et al. 2011). Fecundity and egg size varies with body size, but in the Klamath River, females have been documented to lay 59,000-242,000 eggs (Van Eenennaam et al. 2006).

Dependency on habitat and/or other species

Workshop participants scored the resource's dependency on habitat and/or other species, and these scores were used calculate climate change sensitivity.

> ***Overall degree of specialization***: *Moderate (high confidence)*
> ***Dependency on one or more sensitive habitat types:*** *Moderate-high (moderate confidence)*
>> ***Description of habitat:*** *Deep pools (adults) and floodplains (juveniles). Upper Sacramento River to Bay for young/juveniles/adults. Adults also depend on ocean for food and growth.*
>
> ***Dependency on specific prey or forage species:*** *Low (high confidence)*
> ***Dependency on other critical factors that influence sensitivity:*** *High (high confidence)*
>> ***Description of other dependencies:*** *Ocean condition. Interaction with other populations.*

Although there is a small spawning population in the Feather River (Seesholtz et al. 2014), green sturgeon in the southern distinct population segment primarily utilize the Sacramento River for breeding (NMFS 2015). Spawning occurs in cool, deep pools in the upper Sacramento mainstem that contain some type of small to medium-type substrate (Poytress et al. 2010, 2011). After hatching and metamorphosis, juveniles remain in the river for 6-24 months before migrating to coastal habitats (Radtke 1996). Adults and subadults utilize a variety of coastal bays and estuaries and marine habitats along the Pacific Coast (reviewed in NMFS 2015). Both juveniles and adults are opportunistic prey generalists, primarily acting as benthic feeders (NMFS 2015).

Adaptive Capacity

Workshop participants scored the resource's adaptive capacity and the overall score was used to calculate climate change vulnerability.

Adaptive Capacity Component	Score
Extent, Status, and Dispersal Ability	Moderate-high
Landscape Permeability	Low
Intraspecific Species Diversity	Moderate-high
Resistance	Moderate-high

Overall Scores	Moderate

Extent, status, and dispersal ability

Overall degree of extent, integrity, connectivity, and dispersal ability: *Moderate-high (high confidence)*
Geographic extent: *Transboundary (high confidence)*
Health and functional integrity: *Endangered (high confidence)*
Population connectivity: *Continuous (high confidence)*
Dispersal ability: *High (high confidence)*
Maximum annual dispersal distance of species: *>100 km (low confidence)*

There are two distinct population segments (DPS) of green sturgeon. The southern DPS exists south of the Eel River, has a smaller population, and is listed as threatened under the Endangered Species Act (NMFS 2006). The Northern DPS exists in and from the Eel River north, has a slightly larger population size, and is a federal Species of Concern, but not listed under the Endangered Species Act (NMFS 2015). Both of these distinct populations segments interact in the ocean environment (NMFS 2015), particularly in estuaries off the coast of Washington and Oregon (Israel et al. 2009). Green sturgeon are wide-ranging, particularly during their oceanic phase; telemetry work has shown that this species migrates along the Pacific Coast from as far as from Monterey Bay, California, to Alaska (Moser & Lindley 2006; Lindley et al. 2008, 2011). There is no research available on homing and it is believed that homing, if present in green sturgeon, is not as strong as in salmon. All green sturgeon populations are connected physically, but it is unknown if they are also genetically connected throughout the range[1].

Within the Sacramento River, adult green sturgeon show high interannual variability in holding area use, but they typically use only a few number of areas relative to the total number believed to be suitable (NMFS 2015). These congregation patterns make them vulnerable to significant population losses if an extreme natural event and/or poaching event were to occur (NMFS 2015).

Landscape permeability

Overall landscape permeability: *Low (high confidence)*
Impact of various factors on landscape permeability:
Dams, levees, & water diversions: *High (high confidence)*

Dams, levees and water diversions can impede or block upstream migration and access to cold-water refugia through several mechanisms and/or cause sturgeon mortality through entrainment or impingement (reviewed in NMFS 2015). Several dams are known to block and reduce upstream migration (NMFS 2015), and modeling by Mora et al. (2009) indicates that several dams likely restrict sturgeon access to historic and potentially new upstream spawning habitat in several Sacramento River tributaries.

Species diversity

Overall species diversity: *Moderate-high (high confidence)*
Diversity of life history strategies: *High (high confidence)*
Genetic diversity: *Moderate-high (high confidence)*
Behavioral plasticity: *High (high confidence)*
Phenotypic plasticity: *Low (high confidence)*

Green sturgeon display behavioral plasticity and fairly diverse life history strategies. For example, post-spawning, adults may either rapidly migrate back to the ocean or hold over until fall and winter flows (Heublein et al. 2009). Similarly, adult fish use different riverine holding areas from year-to-year (NMFS 2015), and adults/subadults use a variety of estuarine environments during the oceanic phase of their life cycle (Moser & Lindley 2006; Lindley et al. 2008, 2011). There is some genetic distinction between the southern DPS and the northern DPS (Israel et al. 2009). Genetic work is needed to determine the degree of relatedness between green sturgeon in North America (Eastern Pacific) and Sakalin sturgeon (Western Pacific); the largest population is in the Amur River in Russia[1].

Resistance

Resistance to stresses/maladaptive human responses: *Moderate-high (high confidence)*

Green sturgeon are not very resistant to dams, water diversions, water management activities, and human land use activities that affect habitat availability or quality (NMFS 2006, 2015). Adults and juveniles are fairly resilient to shifts in dissolved oxygen, temperature, and salinity, while egg and larval stages are slightly more vulnerable (reviewed in NMFS 2015).

Management potential

Workshop participants scored the resource's management potential.

Management Potential Component	Score
Species value	Moderate
Societal support	Low-moderate
Agriculture & rangeland practices	Moderate
Extreme events	Low
Converting retired land	Low
Managing climate change impacts	Low
Overall Score	**Low**

Value to people

Value to people: *Moderate (moderate confidence)*
Description of value: *Value is ecological, as they are generally not fished (except by Native Americans on the Klamath River).*

Support for conservation

Degree of societal support for management and conservation: *Low-moderate (high confidence)*
Description of support: *Regulatory and legislative, but little financial support. Federal and state-listed special status.*

Degree to which agriculture and/or rangelands can benefit/support/increase resilience: *Moderate (high confidence)*
Description of support: *Floodplain access and water management.*

Degree to which extreme events (e.g., flooding, drought) influence societal support for taking action: *Low (high confidence)*

Likelihood of converting land to support species

Likelihood of (or support for) converting retired agriculture land to maintain or enhance species: *Low (high confidence)*

Likelihood of managing or alleviating climate change impacts: *Low-moderate (high confidence)*
Description of likelihood: *Very unlikely as management of water and flood systems is managed for winter-run Chinook salmon.*

There is regulatory support for managing green sturgeon since the southern distinct population is federally threatened under the Endangered Species Act (NMFS 2006). Conservation hatcheries could benefit this species by collecting wild broodstock, raising embryos to larvae stage, then releasing in regional rivers[1]. Dam releases can also be timed to support green sturgeon spawning migrations (Israel & Klimley 2008), and water management activities can be coordinated to minimize negative affects on green sturgeon migration and spawning and rearing habitat (Heublein et al. 2009; NMFS 2015), although these practices may be at odds with human water use priorities (NMFS 2015). In addition, management priorities for green sturgeon may conflict with existing or intended management actions for other cold-water species, such as the Chinook salmon (Industrial Economics Incorporated 2009).

Literature Cited

Allen PJ, Hodge B, Werner I, Cech J Joseph J. 2006. Effects of ontogeny, season, and temperature on the swimming performance of juvenile green sturgeon (Acipenser medirostris). Canadian Journal of Fisheries and Aquatic Sciences **63**:1360–1369.

Brown K. 2006. Evidence of spawning by green sturgeon, Acipenser medirostris, in the upper Sacramento River, California. Environmental Biology of Fishes **79**:297–303.

C2HM HILL. 2014. West-wide climate risk assessment: Sacramento and San Joaquin Basins climate impact assessment. Report prepared for the U.S. Department of the Interior, Bureau of Reclamation. Available from http://www.usbr.gov/watersmart/wcra/docs/ssjbia/ssjbia.pdf.

Diffenbaugh NS, Swain DL, Touma D. 2015. Anthropogenic warming has increased drought risk in California. Proceedings of the National Academy of Sciences **112**:3931–3936.

Haller LY, Hung SSO, Lee S, Fadel JG, Lee J-H, McEnroe M, Fangue NA. 2015. Effect of nutritional status on the osmoregulation of green sturgeon (Acipenser medirostris). Physiological and Biochemical Zoology: Ecological and Evolutionary Approaches **88**:22–42.

Heublein JC, Kelly JT, Crocker CE, Klimley AP, Lindley ST. 2009. Migration of green sturgeon, Acipenser medirostris, in the Sacramento River. Environmental Biology of Fishes **84**:245–258.

Industrial Economics Incorporated. 2009. Economic analysis of the impacts of designating critical habitat for the threatened southern distinct population segment of North American green sturgeon. Report prepared for the National Marine Fisheries Service. Available from http://www.westcoast.fisheries.noaa.gov/publications/protected_species/other/green_sturgeon/g_s_critical_habitat/gschd_finaleconomicrpt.pdf.

Israel JA, Bando KJ, Anderson EC, May B. 2009. Polyploid microsatellite data reveal stock complexity among estuarine North American green sturgeon (Acipenser medirostris). Canadian Journal of Fisheries and Aquatic Sciences **66**:1491–1504.

Israel JA, Klimley AP. 2008. Life history conceptual model for North American green sturgeon (Acipenser medirostris). California Department of Fish and Game, Delta Regional Ecosystem Restoration and Implementation Program. Available from http://www.deltarevision.com/Issues/fish/DRERIP_GreenSturgeon_dec2008_reviewed[1].pdf.

Knowles N, Cayan DR. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. Geophysical Research Letters **29**:1891.

Kohlhorst DW, Botsford LW, Brennan JS, Cailliet GM. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (Acipenser transmontanus). Pages 277–293 in P. Williot, editor. Acipenser. CEMAGREF.

Linares-Casenave J, Werner I, Van Eenennaam JP, Doroshov SI. 2013. Temperature stress induces notochord abnormalities and heat shock proteins expression in larval green sturgeon (Acipenser medirostris Ayres 1854). Journal of Applied Ichthyology **29**:958–967.

Lindley ST et al. 2011. Electronic tagging of green sturgeon reveals population structure and movement among estuaries. Transactions of the American Fisheries Society **140**:108–122.

Lindley ST, Moser ML, Erickson DL, Belchik M, Welch DW, Rechisky EL, Kelly JT, Heublein J, Klimley AP. 2008. Marine migration of North American green sturgeon. Transactions of the American Fisheries Society **137**:182–194.

Linville RG. 2006. Effects of excess selenium on the health and reproduction on White sturgeon (Acipenser medirostris): implications for San Francisco Bay-Delta. Ph.D. University of California, Davis, Davis, CA.

Mayfield RB, Cech Jr JJ. 2004. Temperature effects on green sturgeon bioenergetics. Transactions of the American Fisheries Society **133**:961–970.

Mora EA, Lindley ST, Erickson DL, Klimley AP. 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 ML, Lindley ST. 2006. Use of Washington estuaries by subadult and adult green sturgeon. Environmental Biology of Fishes **79**:243–253.

Moyle PB, Foley PJ, Yoshiyama RM. 1992. Status of green sturgeon, Acipenser medirostris, in California. University of California, Davis, Davis, CA.

National Marine Fisheries Service. 2006. Endangered and threatened wildlife and plants; threatened status for southern distinct population segment of North American green sturgeon. Federal Register **71**:17757–17766.

National Marine Fisheries Service. 2015. Southern distinct population segment of the North American green sturgeon (Acipenser medirostris); 5-year review: summary and evaluation. National Marine Fisheries Service, West Coast Region, Long Beach, CA. Available from http://www.westcoast.fisheries.noaa.gov/publications/protected_species/other/green_sturgeon/8.25.2015_southern_dps_green_sturgeon_5_year_review_2015.pdf.

Poytress WR, Gruber JJ, Van Eenennaam J. 2010. 2009 Upper Sacramento River green sturgeon spawning habitat and larval migration surveys. Annual Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation. Red Bluff, CA. Available from https://www.fws.gov/redbluff/MSJM%20Reports/GST/2009_FWS_GS_Final_Report.pdf.

Poytress WR, Gruber JJ, Van Eenennaam J. 2011. 2010 Upper Sacramento River green sturgeon spawning habitat and larval migration surveys. Annual Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation. Red Bluff, CA. Available from https://www.fws.gov/redbluff/MSJM%20Reports/GST/2010_FWS_GS_Final_Report.pdf.

Poytress WR, Gruber JJ, Van Eenennaam J. 2012. 2011 Upper Sacramento River green sturgeon spawning habitat and larval migration surveys.. Annual Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation. Red Bluff, CA. Available from https://www.fws.gov/redbluff/MSJM%20Reports/GST/2011_FWS_GS_Final_Report.pdf.

Radtke LD. 1996. Distribution of smelt, juvenile sturgeon and starry flounder in the Sacramento – San Joaquin Delta. Pages 115–119 in S. L. Turner and D. W. Kelley, editors. Ecological studies of the Sacramento - San Joaquin Delta, Part II. California Department of Fish and Game.

Sardella BA, Kültz D. 2014. The physiological responses of green sturgeon (Acipenser medirostris) to potential global climate change stressors. Physiological and Biochemical Zoology: Ecological and Evolutionary Approaches **87**:456–463.

Seesholtz AM, Manuel MJ, Eenennaam JPV. 2014. First documented spawning and associated habitat conditions for green sturgeon in the Feather River, California. Environmental Biology of Fishes **98**:905–912.

State of Oregon Department of Environmental Quality. 2012. Rogue Basin water quality status and action plan summary 2012. Medford, OR. Available from http://www.deq.state.or.us/wq/watershed/Docs/RogueSummary.pdf.

Van Eenennaam J, Linares-Casenave J, Deng X, Doroshov SI. 2005. Effect of incubation temperature on green sturgeon embryos, Acipenser medirostris. Environmental Biology of Fishes **72**:145–154.

Van Eenennaam JP, Linares J, Doroshov SI, Hillemeier DC, Willson TE, Nova AA. 2006. Reproductive conditions of the Klamath River green sturgeon. Transactions of the American Fisheries Society **135**:151–163.

Vaz PG, Kebreab E, Hung SSO, Fadel JG, Lee S, Fangue NA. 2015. Impact of nutrition and salinity changes on biological performances of green and white sturgeon. PLOS ONE **10**:e0122029.

Williams AP, Seager R, Abatzoglou JT, Cook BI, Smerdon JE, Cook ER. 2015. Contribution of anthropogenic warming to California drought during 2012-2014. Geophysical Research Letters **in press**:1–10.

[1] Expert opinion, Central Valley Landscape Conservation Project Vulnerability Assessment Workshop, Oct. 8-9, 2015.