FINAL REPORT ◦ JUNE 2017

Status, Distribution, and Population of Origin of Green Sturgeon in the Eel River: Results of 2014–2016 Studies

PREPARED FOR

NOAA Fisheries
Office of Protected Resources

PREPARED BY

Stillwater Sciences
and
Wiyot Tribe Natural Resources Department

Stillwater Sciences

ACKNOWLEDGMENTS

This ongoing project is led by the Wiyot Tribe Natural Resources Department (NRD), with technical assistance from Stillwater Sciences and Sweet River Sciences. Principal investigators were Stephen Kullmann of the Wiyot Tribe and Dr. Joshua Strange of Stillwater Sciences and Sweet River Sciences. Project staff to date include Stephen Kullmann, Tim Nelson, Eddie Koch, and Vincent DiMarzo of the Wiyot Tribe NRD; Troy Fletcher Jr.; and Abel Brumo, Liam Zarri, and Ethan Mora of Stillwater Sciences. Funding was provided by NOAA Fisheries Species Recovery Grants to Tribes. California Department of Fish and Wildlife provided in-kind services for the helicopter survey as well as input into project development from CDFW biologists Allan Renger and Scott Downie. NOAA Fisheries Southwest Science Center provided a DIDSON unit as in-kind support and Dr. Carlos Garza's lab at the Southwest Science Center provided genetic testing and analysis to identify the population of origin.

For copies of this report or project inquiries, please contact:

Wiyot Tribe Natural Resources Department at
www.wiyot.us/programs-and-services/natural-resources/fisheries-projects
(707) 733-5055

or

Stillwater Sciences at
www.stillwatersci.com
(707) 822-9607

Suggested citation:
Stillwater Sciences and Wiyot Tribe Natural Resources Department. 2017. Status, distribution, and population of origin of green sturgeon in the Eel River: results of 2014–2016 studies. Prepared by Stillwater Sciences, Arcata, California and Wiyot Tribe, Natural Resources Department, Loleta, California, for National Oceanic and Atmospheric Administration, Fisheries Species Recovery Grants to Tribes, Silver Springs, Maryland.

Cover photos: Green sturgeon research activities on the mainstem Eel River. Clockwise from upper left: custom cataraft near Island Mountain; sonar survey above the North Fork Eel River; large pool near McCann; and tagging an adult green sturgeon in the Eel River estuary.

Table of Contents

Tables

Figures

Appendices (*available upon request*)

1 INTRODUCTION

1.1 Project Background and Need

Green sturgeon (*Acipenser medirostris*) are found in the coastal waters and rivers of western North America where they feed in coastal marine and estuarine environments and spawn in selected large rivers (Adams et al. 2002, Moyle 2002). Their marine distribution ranges from Ensenada, Mexico to the Bering Sea, Alaska (Scott and Crossman 1973, Moyle 2002), but the only confirmed spawning aggregations were documented in the Rogue River of Southern Oregon (Erickson et al. 2002) and adjacent Klamath River of Northern California (Benson et al. 2007), plus the Sacramento River of California's Central Valley (Kohlhorst 1976, Brown 2007). Genetic studies have led to the classification of two distinct population segments (DPS): the Northern DPS, which includes fish spawning in the Rogue and Klamath rivers, and the Southern DPS, comprising fish spawning in the Sacramento River (Israel et al. 2004). The Southern DPS was listed as threatened under the Endangered Species Act in 2006 (NMFS 2006), largely because only one spawning population is known to occur, while the Northern DPS is listed as a state and federal species of concern due to multiple spawning populations but many of the same general threats. Green sturgeon are a long-lived, late-maturing anadromous fish species, and as such they are vulnerable to freshwater habitat loss and exploitation and population recovery has the potential to be slow (Moyle 2002, Adams et al. 2002, NMFS 2010). Adult green sturgeon generally return to spawn in rivers in late winter through the early summer and spawn every two to six years, with spawning intervals of three to four years being the most common (Moyle 2002, Adams et al. 2002, NMFS 2010, Doukakis 2014).

The Eel River, in Northern California, is one of the larger rivers in the state and historically had an apparently robust and important spawning run of green sturgeon, although inferences about population size are impossible because of the lack of historical data (Adams et al. 2002). Contemporary fisheries surveys from the Eel River would occasionally record some green sturgeon adults or juveniles. The general consensus was that green sturgeon in the Eel River had become exceedingly rare and it was uncertain if these sightings represented a few stray fish from other spawning rivers in the area, or signified an actual persistent and distinct spawning run (Adams et al. 2007). In the late 1960s, anadromous fish outmigration trapping studies conducted by the CDFW documented juvenile green sturgeon approximately 100 km upstream on the mainstem Eel River (Puckett 1976). Similarly, CDFW documented multiple adult green sturgeon during the summer in the mainstem Eel River in the same general areas, a finding consistent with spawning run behavior. Also, sporadic sightings of adult green sturgeon by boaters and fishermen have occurred historically and in recent years, with observations of fish occurring in the lower mainstem as well as over 100 km upstream. In conceiving this project, we hypothesized that contemporary sightings of green sturgeon in the Eel River represented a persistent and distinct, albeit undocumented, spawning run and we predicted that a systematic, multi-year survey would demonstrate this.

Moyle et al. (1992) hypothesized that the green sturgeon spawning run on the Eel River was completely lost after the 1964 flood, which caused severe aggradation and decreased pool depths. The Biological Review Team (BRT) convened by the National Marine Fisheries Service (NMFS) concluded that green sturgeon of Eel River had certainly suffered severe declines, but some members of the BRT were not convinced that Eel River green sturgeon were fully extirpated (NMFS 2005). In the event that green sturgeon were persisting in the Eel River, there was unresolved debate among the BRT as to whether or not this would constitute a "significant portion of the species' range," with the lack of historical or current spawning data hindering resolution of that debate (NMFS 2005). The most recent status review for Northern DPS green sturgeon showed no evidence for changing their status or new evidence regarding presence of a spawning run in the Eel River (Doukakis 2014).

Although the Eel River was officially designated as part of the Northern DPS (critical habitat for Southern DPS starts south of the Eel River) (NMFS 2010, Doukakis 2014) given its proximity to the Klamath River, there was no direct evidence to verify that any green sturgeon in the Eel River were or actually are of Northern DPS genetics. While the Eel River is indeed proximate to the Klamath River, it is even closer to Humboldt Bay, which is a documented feeding habitat for both Southern and Northern DPS (Lindley et al. 2011). Therefore, it is possible that any green sturgeon in the Eel River could be of Southern DPS origin or a mix of both.

NOAA's recovery planning document for the Southern DPS of green sturgeon (NMFS 2010) states: "*In order to establish a recovery plan for the species, the current status of that species must be understood.*" In order to understand the population status and effectively manage the species, it is necessary to determine whether any green sturgeon that spawn in the Eel River are part of the Northern DPS, as presumed without direct evidence, whether they are part of the Southern DPS, or whether they are a mix. All possible outcomes would be significant: (1) if they are Northern DPS, this would add a third, persistent spawning river/population to that DPS besides the Klamath and Rogue rivers; (2) if they are Southern DPS, this would add a vital second spawning population besides the Sacramento River, which has important implications for population resiliency; and (3) if they are a mix, it would be the first documented mixed spawning run.

In addition to determining the population of origin, it is important to document a spawning run, including the timing and locations, and if possible, spawning success, all of which would allow for a more accurate assessment of the status of green sturgeon in the Eel River, as well as further evaluation of potential threats and recovery actions. Another important question is whether the Eel River estuary, both the riverine and marine portions, is being used as rearing and feeding habitat for one or both DPSs of green sturgeon, similar to nearby Humboldt Bay (mixed), the Umpqua River estuary (Northern DPS only), or the Klamath River (mixed in marine estuary, Northern DPS only in riverine estuary) (Lindley et al. 2008, Israel et al. 2009, Lindley et al. 2011, Doukakis 2014).

1.2 Project Goals and Objectives

The goal of this project is to determine the current status and population of origin of green sturgeon in the Eel River of Northern California. This report summarizes the research activities and findings for study years 2014 to 2016 and makes recommendations for further research and monitoring of green sturgeon in the Eel River.

The objectives of this project are to: (1) determine the presence, timing, and locations of green sturgeon spawning and holding in the mainstem Eel River; (2) evaluate the use of the Eel River estuary (riverine and marine) by adult green sturgeon; and (3) determine the population(s) of origin (Southern DPS vs. Northern DPS) of any sturgeon documented in the Eel River.

1.3 Study Approach

The study approach to meet the project objectives included the following primary tasks: (1) mobile DIDSON sonar surveys; (2) acoustic bio-telemetry tagging and monitoring; and (3) determination of population of origin through genetic testing. This study was conducted over a three-year period from 2014 through 2016 to provide sufficient time to collect baseline data to meet the study objectives given the extended and variable spawning periodicity of green sturgeon.

Specific research activities included in the project were: (1) review of background scientific information and extant tribal oral histories related to green sturgeon (2014); (2) assessment of spawning habitat availability and limitations by cataloging pools with suitable depths (2014, 2016); (3) conducting a presence and enumeration survey of adults on the mainstem Eel River over 192 river kilometers using a mobile DIDSON sonar camera (2014, 2016); (4) tagging adults with acoustic telemetry transmitters with a 10-year life-span (2015); (5) identifying population of origin of tagged adult green sturgeon using genetic analysis of tissue samples (2015); and (6) deploying an acoustic receiver detection network at strategic sites in the marine, estuarine, and riverine migration corridor that monitored the movements of acoustically-tagged adult green sturgeon, whether from this study or from other studies in different locations (2014–2016).

1.4 Study Area

While the greater study area for this project will ultimately include any areas used by green sturgeon in the Eel River basin, the study area reported herein was the mainstem Eel River from the confluence of the Middle Fork Eel River at river kilometer 192 (Dos Rios) to the Pacific Ocean and the nearshore marine portion of the estuary within 2 km of the mouth.

Draining an area of 9,534 km^2, the Eel River is California's third-largest watershed and is located between the Russian, Sacramento, Mad, and Mattole river watersheds. The Eel River basin is divided into the following major sub-basins: Lower Eel River, Van Duzen River, Lower Mainstem Eel River, South Fork Eel River, Middle Main Eel River, North Fork Eel River, Middle Fork Eel River, and Upper Mainstem Eel River (Figure 1-1).

Annual precipitation in the watershed averages 40 inches (102 cm) in the coastal lowlands to 80–100 inches (203–254 cm) at higher elevations. The climate classification of the basin is Coastal Mediterranean, marked by a rainfall pattern of wet winters and dry summers. During the period of record (starting in 1910), discharge in the lower Eel River near Scotia (USGS gage 11477000) averaged 19,900 cubic feet per second (cfs) for January and only 138 cfs for September, with a peak discharge of 752,000 cfs in December of 1964 and a minimum of near zero in August of 2015. Average annual water yield for the watershed at Scotia, which is upstream of the Van Duzen River, is estimated at 5.5 million acre-feet, although annual variation is considerable with wet years having a yield of over 12.5 million acre-feet and dry years of less than 0.5 million acre-feet. Most of the sub-basins in the Eel River are influenced by proximity to the Pacific Coast with winter-rainfall dominated hydrographs, although the Middle Fork Eel River, as well as the North Fork Eel River to some extent, also have a significant spring snowmelt signature in their hydrographs as they drain the sub-alpine Yolly Bolly Mountains.

Under current conditions, however, the spring snowmelt hydrograph is muted in the Upper Mainstem Eel River by Pacific Gas &Electric's (PG&E) Potter Valley Project, which also serves to divert water into the Russian River for consumptive use. An average of approximately 219 cfs is diverted from the Upper Mainstem Eel River and routed south into the Russian River basin, which has amounted to an average of approximately 160,000 acre-feet per year. The Potter Valley Project consists of two dams: the smaller Cape Horn Dam constructed in 1907 forms Van Arsdale Reservoir, which serves as the point of diversion and a fish counting stations for salmonids; 17 km upstream, the larger Scott Dam constructed in 1912 forms Pillsbury Reservoir, used for hydroelectric generation. Cape Horn Dam has fish passage for salmonids while Scott Dam is a total barrier to anadromous fish. The Potter Valley Project entered into the Federal Energy Regulatory Commission's license review and renewal process in 2017.

The historical distribution of green sturgeon in the Eel River basin is not known; however, with the exception of likely barriers to adult upstream migration, the mainstems of the larger river channels should be accessible to adults. Known large and steep rapids expected to limit adult migration of green sturgeon include Goat Rock on the Van Duzen, Split Rock on the North Fork Eel, and Coal Mine Falls on the Middle Fork Eel River. These rapids are similar in magnitude to rapids that are known barriers to upstream migration for adult green sturgeon in the Klamath and Trinity rivers (Dr. Joshua Strange, Sweet River Sciences, pers. obs.). The mainstem Eel River and South Fork Eel River have no notable larger rapids that appear likely to be a barrier to adult green sturgeon migration, but eventually become too small and steep for adult sturgeon. No other tributaries are large enough to be considered as likely green sturgeon habitat. The mainstem Eel River within the study area comprises two sub-basins, the lower and the middle main river, which roughly corresponds to major changes in the character of the river. The lower sub-basin is characterized as being wider with very low gradient, dominated by gravel and fine sediments, with easy access and regular human settlements; in contrast, the middle sub-basin is characterized as being relatively narrower with rapids and higher gradient, dominated by a mix of bedrock and boulders with finer sediments, with minimal access and sparse human settlements. Tide-water influence extends upriver to the vicinity of Fern Bridge.

Landscapes in the basin vary from extensive estuarine habitats of the lower Eel River (tidal wetlands, freshwater marshes, sand dunes, grasslands) to redwood and Douglas-fir dominated forests mixed with hardwoods such as madrone in the coastal mountains, grassland and oak woodlands further inland, and sub-alpine mountains in the headwaters of the interior sub-basins. The geology of the watershed is naturally unstable, characterized by unconsolidated Franciscan mélange marine sediments that coupled with the high rate of uplift of the Costal Range results in the Eel River having an exceptionally high sediment load (Brown and Ritter 1971). Land uses in the watershed include ranching and livestock grazing, timber management and milling, light industrial, rural and residential development, recreation, gravel extraction, and agriculture including vineyards and commercial marijuana cultivation. There are no large urban areas in the Eel River watershed, and the largest population centers are Fortuna, Garberville/Redway, and Willits.

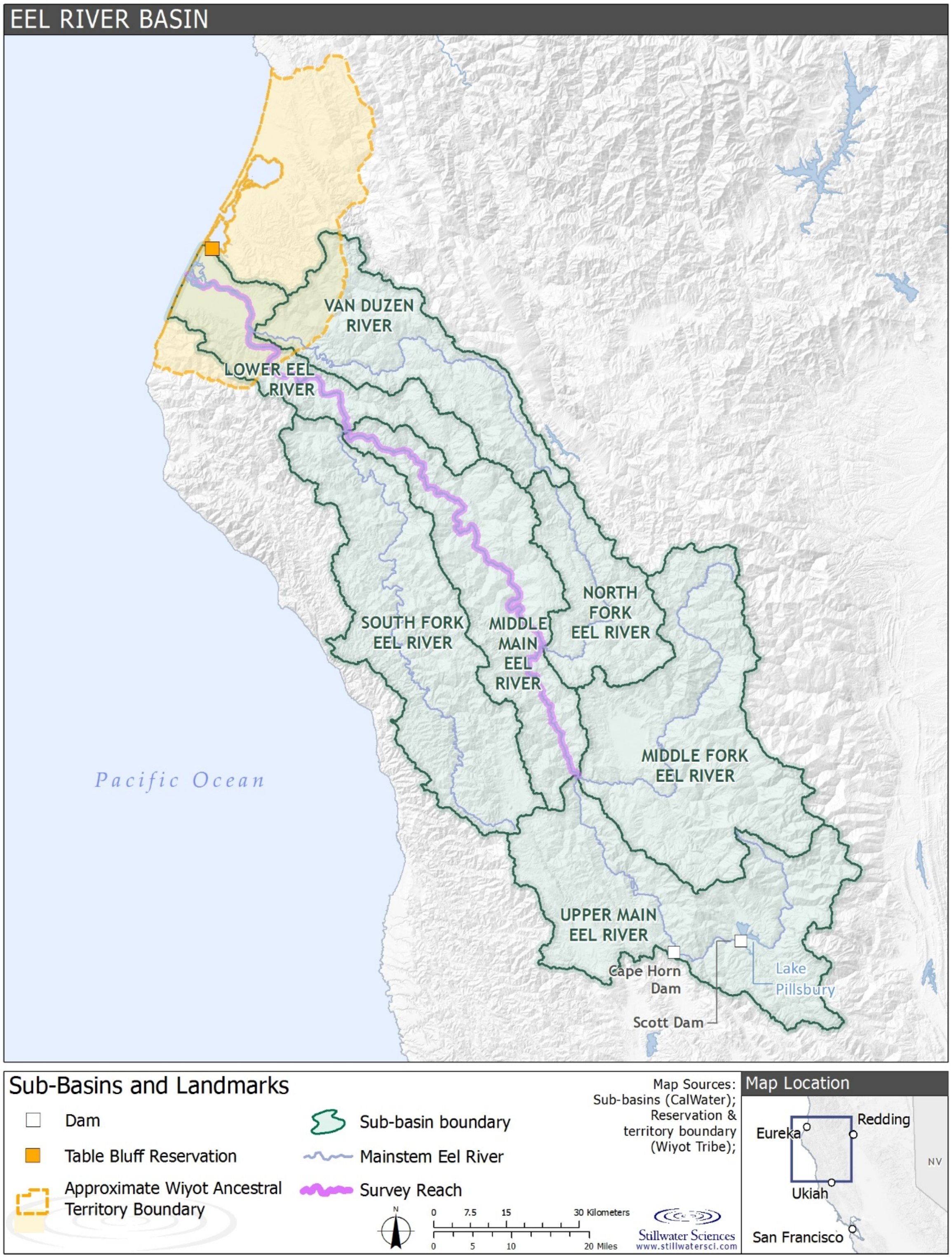

Figure 1-1. Map of the Eel River watershed showing major sub-basins, the 192-km survey reach on the mainstem, and the perimeter of Wiyot Ancestral Territory.

1.5 Green Sturgeon Distribution and Life History

1.5.1 Distribution

North American green sturgeon are a widely distributed anadromous and marine-oriented species found in nearshore waters from Baja California to the Bering Sea (NMFS 2009a, Lindley et al. 2011). There are two distinct population segments of green sturgeon: (1) a Northern DPS consisting of populations originating from coastal watersheds northward of the Eel River in California, with documented spawning populations in the Klamath and Rogue rivers; and (2) a Southern DPS consisting of populations originating from coastal watersheds south of the Eel River, with the only known spawning population being in the Sacramento River Basin (NMFS 2006, Seesholtz et al. 2015). The distributions of both the Northern and Southern DPSs of green sturgeon overlap outside of their natal rivers where they congregate to feed in coastal estuaries and bays (Lindley et al. 2011). Notable feeding areas include Humboldt Bay, Columbia River estuary, Umpqua River estuary, Willapa Bay, and Grays Harbor (Heublein et al. 2009, Lindley et al. 2011).

Heublein et al. (2009) tracked tagged Southern DPS green sturgeon spawning migrations that extended up to Cows Creek (river kilometer [rkm] 450) in the Sacramento River. Beamesderfer et al. (2004) and Brown (2006) reported that eggs, larvae, and post-larval green sturgeon are commonly captured during sampling efforts in the Sacramento River. Juveniles have also been observed in the Sacramento River around the Red Bluff Diversion Dam (NMFS 2009b). Northern DPS adult green sturgeon have been observed as far upstream on the Klamath River as Ishi Pishi Falls at rkm 108 (Benson et al. 2007) and upstream on the Rogue River at least as far as Rainie Falls at rkm 107 (Erickson and Webb 2007).

1.5.2 Adult freshwater migration

Adult green sturgeon generally return to spawn in rivers in late winter through early summer and spawn every two to six years, with spawning intervals of three to four years being the most common (Moyle 2002, Adams et al. 2002, NMFS 2010, Doukakis 2014). In the Sacramento River, Heublein et al. (2009) reported that sturgeon lingered at the apex of their riverine migrations for 15–41 days, presumably engaging in spawning behavior and subsequently holding prior to moving back downstream.

Following spawning, during summer and fall months when temperatures were 15–23°C (59–73°F), green sturgeon in the Rogue River were found to generally reside in deep (>5 m) pools with low or no currents (Erickson et al. 2002). Post-spawned adults have also been observed in in the Klamath and Trinity rivers, holding in deep pools with areas of low velocity and low to moderate currents (Benson et al. 2007, McCovey 2011, Dr. Joshua Strange, Sweet River Sciences, pers. obs.). Some adult sturgeon move back downstream to the estuary and ocean soon after spawning when river flows are still elevated by snowmelt, but others have been observed to hold in the river until the fall when temperatures decrease and flows increase with precipitation (Heublein et al. 2009, NMFS 2009b). Timing of emigration in the Klamath River is related to increased discharge, particularly with the first fall freshets (Benson et al. 2007, McCovey 2011). In the Sacramento River, some tagged adult green sturgeon remained through February of the year following their spawning run before moving downstream to the ocean with increased winter flows (NMFS 2009b).

1.5.3 Spawning

Green sturgeon are a long-lived, late-maturing anadromous fish species, and as such they are vulnerable to freshwater habitat loss and exploitation, and population recovery has the potential to be slow (Moyle 2002, Adams et al. 2002, NMFS 2010). Conversely, being long-lived and having an extended and variable spawning periodicity of 2–6 years allows sturgeon to be more resilient in the face of variably suitable environmental conditions and periods with poor river conditions.

Spawning adult green sturgeon prefer pools that are >16.4 ft (5 m) deep with complex hydraulic features and upwelling, bedrock shelves, and cobble/boulder substrate (Moyle 2002, Adams et al. 2002, NMFS 2005, Heublein et al. 2009). Substrates suitable for egg deposition and development include bedrock sills and shelves, boulders, or cobbles and gravel with interstices or irregular surfaces to "collect" eggs, to provide protection from predators, and to be free of excessive silt and debris that could smother eggs during incubation (NMFS 2005).

Based on documented spawning locations, spawning behavior, and habitat requirements for green sturgeon embryo development, reproductive females likely select spawning areas with turbulent, high velocities near low velocity resting areas (Israel and Klimley 2008). Eggs are broadcast and externally fertilized in relatively fast water at depths generally greater than 10 ft (3 m) (Moyle 2002). Poytress et al. (2011) conducted underwater videography in three confirmed green sturgeon spawning pools in the Sacramento River and found that these pools generally had highly turbulent flow in the upstream area that flowed over bedrock or hardpan, with downstream areas having lower velocities and substrates composed of cobble, gravel, and sand.

1.5.4 Egg incubation

Female green sturgeon produce 59,000–242,000 eggs that are about 0.17 inches (4.3 millimeters [mm]) in diameter (Van Eenennaam et al. 2004). Eggs hatch 6–8 days after fertilization (Deng et al. 2002). Optimal water temperatures for the development, growth, and survival of green sturgeon eggs and larvae are between 15–19°C (59–66°F) (Mayfield and Cech 2004). Van Eenennaam et al. (2004) reported water temperatures between 17–18°C (63–64°F) to be the upper limit of thermal optima for green sturgeon embryos, with greater temperatures affecting development and hatching success. Similarly, Doroshov et al. (2004) found high survival rates for a temperature range of 16–19°C (61–66°F), but abnormalities increased significantly above 19°C (66°F). Water temperatures greater than 23°C (73°F) have been shown to cause complete mortality before hatch (Van Eenennaam et al. 2004).

1.5.5 Larval development

At hatching, most body systems of green sturgeon larvae are incomplete. Consequently, substantial organogenesis and acquisition of organ functions occur during the larval development stage (Deng et al. 2002). Newly hatched larvae have poor swimming ability and prefer to stay in contact with structure, cover, and dark (very low light) habitat as opposed to open-river bottoms (Kynard et al. 2005, as cited in NMFS 2009b). Larval feeding begins approximately 10 days after hatching when larvae are approximately 1 inch (25 mm) in length (Deng et al. 2002). Larvae begin to display a nocturnal swim-up behavior at 6 days post-hatch, when the rudiments of the pectoral and ventral fins become developed, dorsal and anal fin rays are apparent, yolk of the mid-intestine is depleted, and the mandible begins rhythmic movement (Deng et al. 2002). This swim-up behavior may assist in downstream dispersal to nursery areas (Deng et al. 2002).

Green sturgeon larvae initiate a downstream dispersal migration that begins when they are about 6 to 9 days old and lasts about 12 days (USDI 2008). Trap samples at Red Bluff Diversion Dam and the Glenn-Colusa Irrigation District (GCID) Diversion showed the downstream dispersal of larval green sturgeon in the upper Sacramento River to occur from May through August at sizes ranging from 0.8–2.4 inches (20–60 mm) (Gaines and Martin 2002, CDFG 2002, both as cited in USDI 2008). Larvae occupy bottom habitat with cover during daylight periods, and thus downstream dispersal typically occurs at night (USDI 2008). Poytress et al. (2010) conducted an experimental benthic D-net survey in water that was 8.9–10.8 ft (2.7 to 3.3 m) deep that had a surface velocity of 2.0 feet per second (ft/s), and observed a peak in larval captures between 10 p.m. and 11 p.m. when the water temperature was approximately 15.5°C (60°F).

Larval green sturgeon are regularly captured during the dispersal stage at about two weeks of age at the Red Bluff Diversion Dam (CDFG 2002, as cited in USDI 2008) and are three weeks of age when captured further downstream at the GCID Diversion (USDI 2008). The distance between these two facilities is approximately 34 river miles. Therefore, based on emigration of fish between these two points, the average rate of downstream dispersal by larval green sturgeon during 2002 was approximately 7.9 km (4.9 mi) per day, or more specifically, per night. Assuming that the downstream larval green sturgeon migration reported in USDI (2008) occurs only at night and that there are 9 hours of darkness during the late spring and summer months, then the dispersal rate would be approximately 0.8 ft/s (0.24 m/s).

In a laboratory study of young Kootenai River white sturgeon (*Acipenser transmontanus*), Kynard et al. (2007) found that there is a threshold water velocity needed to trigger larval dispersal; a velocity of 0.2 ft/s (0.07 m/s) was insufficient to trigger downstream dispersal for most larvae, 0.5 ft/s (0.17 m/s) triggered most larvae, and 0.75 ft/s (0.23 m/s) triggered slightly more larvae.

Water temperatures below 11°C (52°F) and above 19°C (66°F) are detrimental for larval green sturgeon development (Doroshov et al. 2004, Van Eenennaam et al. 2004). Doroshov et al. (2004) also determined that water temperatures between 22 and 26°C (72 and 79°F) resulted in notochord deformities in larval green sturgeon. Metamorphosis from the larval to juvenile stage is completed at approximately 45 days post-hatch, when fish range in size from 2.5 to 4.0 inches (6.3–9.9 cm) (Deng et al. 2002).

1.5.6 Juvenile rearing

Juveniles grow rapidly, reaching 12 inches (30 cm) in one year and over 24 inches (60 cm) in 2–3 years (Nakamoto et al. 1995). Very little information is available on the food and nutrient requirements of different life stages of green sturgeon (Klimley et al. 2006). Mayfield and Cech (2004) found that juvenile green sturgeon bioenergetic performance was optimal between water temperatures of 15–19°C (59–66°F) and that swimming performance decreased beyond 19°C (66°F). Allen et al. (2002) reported that river temperatures should not increase beyond 15 to 19°C (59 to 66°F) for optimal juvenile green sturgeon growth rates. Mayfield and Cech (2004) found that juvenile green sturgeon acclimated to temperatures of 11°C (52°F) and 19°C (66°F) did not differ significantly in their thermal preferences (15.9±1.7°C [60.6±3.1°F] and 15.7±2.9°C [60.3±5.2°F], respectively); however, fish acclimated to 24°C (74°F) exhibited a significantly higher preferred temperature (20.4 ±3.1°C [68.7±5.6°F]).

Juveniles migrate downstream (mostly at night) to wintering sites in the fall, ceasing migration at temperatures of 7–8°C (45–46°F) (USDI 2008). Wintering juveniles forage actively at night between dusk and dawn and are inactive during the day, seeking the darkest available habitat

(Kynard et al. 2005, as cited in USDI 2008). Juveniles spend from 1 to 4 years in fresh and estuarine waters of the Sacramento-San Joaquin Delta and disperse into saltwater at lengths of 12–30 inches (30–75 cm) (NMFS 2009a).

1.5.7 Riverine diet

Although specific data are lacking for juvenile green sturgeon, nutritional studies on the closely-related white sturgeon within riverine systems indicate fed on amphipods, bivalves, and fly larvae (NMFS 2009b). These food resources are important for juvenile foraging, growth, and development during their downstream migration to the Delta and bays (NMFS 2009b).

NMFS (2009b) noted that adult green sturgeon may not feed during warm summer months based on the reportedly low hook-and-line fishing success rates. This is corroborated by the skinny condition of post-spawn sturgeon observed in the summer and fall in the Klamath River (Dr. Joshua Strange, Sweet River Sciences, pers. obs.). Capture rates increase in the early fall when water temperatures decrease, which may indicate onset of feeding behavior. An adult green sturgeon captured in the Rogue River was found to have an exoskeleton of a crayfish (*Pacifasticus* spp.) and algae in its digestive tract, but there was no indication of when it was taken (Farr and Kern 2005). Digestive tracts from 46 adult green sturgeon commercially caught during 2000–2004 in the Columbia River contained only algae (Farr and Kern 2005).

1.5.8 Sub-adult and adult ocean residency

Recent analysis from archival tags, acoustic tags, and Oregon bottom trawl logbook records indicate that green sturgeon are widely distributed in the nearshore ocean at depths up to 360 ft (110 m), with most use occurring at depths between 130 and 230 ft (40 and 70 m) (Erickson and Hightower 2007). Sub-adults are non-mature fish that have left their natal rivers and entered the marine environment, which may occur around 2 years of age (Allen et al. 2009). Sexual maturity is reached at around 13 years of age (NMFS 2006). Huff et al. (2011) reported that green sturgeon prefer to occupy highly complex seafloor habitats where the substrate contains a large proportion of boulders. This species travels widely up and down the Pacific Northwest coast, as evidenced by tagged individuals reported in the Columbia and Umpqua river estuaries, Humboldt Bay, Willapa Bay, and Grays Harbor in Washington (Heublein et al. 2009, Lindley et al. 2011).

Three acoustic receivers deployed by the Yurok Tribal Fisheries Department in the ocean offshore of the Klamath River reportedly detected 19 tagged green sturgeon in 2007 (McCovey 2008), with 10 of these detections being originally tagged in San Pablo Bay. Of these 10 fish, none entered the Klamath River. The rest of the detections were from fish tagged in Willapa Bay, Grays Harbor, and the Rogue and Klamath rivers. It is believed that green sturgeon reside in bays and estuaries to feed throughout the summer during years in which they are not making spawning migrations (Moser and Lindley 2007, Lindley et al. 2011).

2 METHODS

2.1 Sonar Surveys

2.1.1 Spring surveys

We conducted boat-based mobile sonar surveys to census adult green sturgeon during the spring spawning season, from the confluence of the Middle Fork Eel River and mainstem of the Eel

River at Dos Rios (rkm 192) to the Pacific Ocean (Figure 1-1). Dos Rios is located above all known historical and recent sightings of green sturgeon within the mainstem Eel River, with the majority of those sightings centered from the confluence of the North Fork (rkm 155) to the confluence of the South Fork (rkm 65) as well as in the estuary. The full spring survey required 7 days to complete and the specific dates of the surveys are reported in the Results section.

We used a waterproof Dual-Frequency Identification Sonar (DIDSON) 300-m sonar camera (Sound Metrics, Bellevue, WA) to detect adult green sturgeon in the mainstem Eel River. The use of a mobile DIDSON to detect and enumerate adult green sturgeon in rivers is a proven technology, including well-developed methods for determining confidence intervals and coefficients of variation (Mora et al. 2015). The advantage of a DIDSON is that it uses dual frequency ultrasonic sonar beams to "see" clearly in highly turbid and/or deep water, conditions where traditional fish detection methods often fail (e.g., divers and underwater video). This ability is especially useful in the Eel River, which is often highly turbid and contains numerous deep pools.

Given that a high percentage of adult green sturgeon over-summer in or near spawning pools, mobile green sturgeon sonar surveys in other rivers (Sacramento, Klamath, and Rogue) have been conducted in the late spring or summer to ensure targeting adults that are not actively migrating. In the Eel River, however, the recession of the wet season hydrograph occurs earlier on average and flows decrease quickly to levels that are non-navigable by the survey vessel due to shallow riffles (<2,000 cfs at Fort Seward gage), thereby requiring that we conduct our boat-based spring sonar surveys in April or May, which was as late in the season as navigation would allow.

We conducted spring sonar surveys using a custom 18-ft (6-m) whitewater cataraft outfitted with rowing oars and 20 HP outboard motor (Figure 2-1). This combination allowed safe navigation through Class III+ rapids and also the ability to motor through long stretches of flatwater or upstream to the top of sampled pools to allow multiple survey passes, as would be done using a jet boat in other green sturgeon rivers. The DIDSON unit was mounted to the center bow of the cataraft with a custom mounting arm that allowed for locking it in the water at the proper depth and full movement to pan left or right and adjust the tilt angle up or down. The entire mounting arm apparatus also had the ability to quickly rotate, which facilitated lifting the DIDSON unit out of the water when navigating rapids and flatwater. Electrical power for the DIDSON unit was provided by deep cycle batteries wired in parallel, stowed in a dry box, and charged with an on-board solar panel. The DIDSON was hooked up to an onboard laptop for real-time viewing of the sonar camera feed. Video of the output was recorded in 2014, but not in 2016 due to budget limitations and the low numbers of fish observed. The boat was manned with a three-person crew: DIDSON operator, general assistant, and boat pilot. All provisions needed for the multi-day floats were stowed on-board due to the remote nature of the river. Fort Seward (rkm 101) provided the best mid-way access point to resupply or switch crew members as needed.

Figure 2-1. Custom motorized whitewater cataraft used for mobile sonar survey in the spring. The DIDSON sonar camera and mounting arm (stowed for rapids) is visible to the right of the photo on the left tube of the boat.

As we traveled downstream we recorded the location and depths of all river meso-habitat units greater than 5-m deep, which were almost exclusively pool units with some deep runs. Location of surveyed units were determined using a Trimble Geo Explore GPS unit, in combination with satellite imagery maps containing a rkm overlay. A portable depth sounder was used to determine water depth (Hummingbird 110 fish finder). All locations greater than 5-m deep were considered potential green sturgeon adult holding and spawning habitat and were surveyed for the presence of adults using the DIDSON. Pools were typically formed in association with a scour feature such as large boulders, bedrock, or constriction, often with a wider expansion feature followed by the downstream alluvial tailout. Deep runs were typically much longer relative to their widths and these locations were often not associated with an expansion bar or alluvial tailout at the downstream end.

In pools, we typically performed a minimum three longitudinal transects with the DIDSON to cover the entire unit. In runs, which were narrower than pools thereby allowing full coverage within the viewing window of sonar, we performed a minimum of one transect. We also sampled some pools less than 5-m deep as time allowed, performing one transect. Sampled units were numbered in the order of their occurrence in the mainstem Eel River study area, from upstream to downstream.

Each transect consisted of driving the survey vessel longitudinally downstream along the thalweg of the habitat unit while the DIDSON operator viewed the sonar data in real-time (Figure 2-2). At the top of each unit, prior to beginning each transect, the boat pilot would signal for the DIDSON operator to deploy the DIDSON and start logging the transect path on the GPS unit. The boat pilot would motor or row downstream at a slow pace (about 5 km/h) and the DIDSON operator would pan and tilt the sonar, viewing as much area as possible during each transect. At the end of each transect, the DIDSON operator would log the GPS path in the Trimble, return the DIDSON to its onboard position, while the assistant would record the maximum depth measured during the transect. The second transect would then be conducted in an upstream direction equidistant between the thalweg and the left or right bank, and the third transect in a downstream direction to the other side of the thalweg.

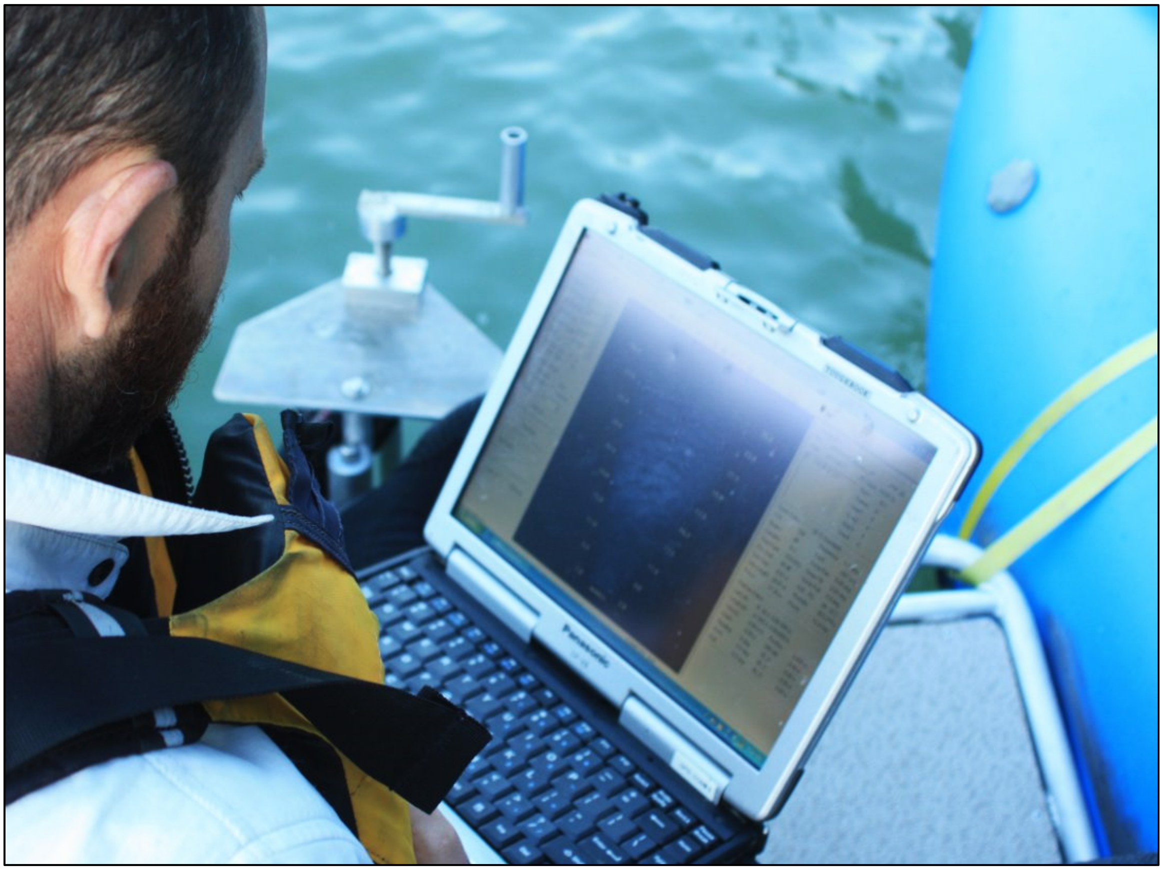

Figure 2-2. Real-time viewing of the DIDSON sonar camera display. The deployed mounting arm attached to the center of the bow of the cataraft frame is visible in the background.

If a potential sturgeon sighting occurred, the DIDSON operator would signal the boat pilot to either hold position or return to the same location while the DIDSON operator sought to confirm the sighting. Sturgeon sightings were generally confirmed by a combination of factors. The most certain sightings are confirmed by a sturgeon-shaped sonar return (pectoral fins and caudal fins visible from a completely perpendicular and oblique viewing angle), the fish changing location with respect to the bottom, a visible tail beat, and the presence of other sturgeon. Sightings of lesser certainty lack any number of these features. Sturgeon lookalikes were typically sunken logs of the right size and general shape, but lacked movement or tailbeats.

We estimated the number of sturgeon in the Eel River study area during our surveys using a quantitative method developed from occupancy modeling techniques as described by Mackenzie et al. (2006). The specific quanititative method for calculating the abundance of sturgeon in our mobile sonar surveys is described in detail by Mora et al. (2015). Ethan Mora was one of the DIDSON operators for this study.

We contend that all of the adult sturgeon that we observed during this study were green sturgeon as opposed to white sturgeon (*Acipenser transmontanus*) based on scute counts and dorsal stripe appearance of the fish we tagged as part of this study and also based on video recordings of adult sturgeon from other researchers and anglers in the Eel River. Based on their biology and habits in the Klamath River, any white sturgeon in the Eel River would be most likely to occur in the estuary or lowermost mainstem river.

2.1.2 Supplemental summer surveys

We supplemented spring surveys with a summer mobile sonar survey of selected pools in the lower reaches of the mainstem Eel River (<rkm 65) that were the most likely to hold sturgeon based on pool depth and professional judgement or had sightings reported in the past. Only pools that could be accessed by road were surveyed as summer low flows prevented navigation of the river between pools. This meant we were unable to conduct summer surveys on some of the more notable large pools identified during the spring survey in the boat-access only reaches further upstream within the middle main sub-basin (rkm 65–rkm 192). Methods for the summer sonar survey were consistent with those described above for the spring survey except that we used a smaller and more portable paddle raft, and pools were surveyed one at time. The summer survey also provided the opportunity to identify locations of over-summering adults that could be subsequently targeted for capture, acoustic tagging, and genetic samples.

2.2 Acoustic Biotelemetry

2.2.1 Acoustic tagging

In 2015, we were able to secure permits and funding to purchase 10 Vemco acoustic tags with 10-year battery life (V16 at 69 kHz). During spring sampling we intercepted migrating adults by placing nets in likely migratory pathways in the lower river below the Van Duzen confluence, whereas during summer sampling we used the results of summer sonar surveys to target specific pools where adults were over-summering below the confluence of the South Fork Eel at rkm 65.

To capture adult green sturgeon, we deployed a 30.5 m x 7.6 m (100 ft x 25 ft) gill net with $7^1/_4$-inch (18.4-cm) mesh in various locations in the estuary and lower reaches of the Eel River. Adult green sturgeon can tolerate a high amount of handling and air exposure, and previous studies indicated high survival of surgically tagged fish (Erickson et al. 2002, Benson et al. 2007).

Tagging was done by surgically inserting the transmitter into the abdominal cavity while the fish was immobilized upside down in a cradle stretcher, followed by suturing (Figure 2-3). Further details on the tagging procedures we used are describe by Benson et al. (2007).

Figure 2-3. Surgical acoustic tagging of an adult green sturgeon captured in the lower mainstem Eel River.

2.2.2 Receiver array

Adult green sturgeon have been surgically tagged with acoustic transmitters by various researchers over the last decade or so (Lindley et al. 2011). Fish have been captured and tagged in the Sacramento, Klamath, and Rogue rivers while presumably en route to spawning areas and thus can be considered as belonging to their respective DPSs. Adults of both Southern DPS and Northern DPS have also been tagged at marine gathering areas in bays and estuaries such as Grays Harbor and Willapa Bay. All of these fish were tagged with Vemco (Bedford, Nova Scotia) transmitters that have the advantage of being easily detectable with any receiver made by Vemco (VR2Ws with the latest codec at 69 kHz). These receivers are deployed underwater and have a detection range of up to 1 km with the advantages of being inexpensive relative to other types of telemetry receivers, easy to operate, rugged, and possess large data storage capabilities. New generations of Vemco transmitters for larger-bodied fish also have a ten-year battery life, creating the ability to track adult green sturgeon migrations and movements over the long-term.

In order to detect and track any adult green sturgeon tagged in other studies or as part of this study, we deployed a small network of five sonic receivers (Vemco VR2Ws) at strategic locations in the mainstem Eel River, the riverine estuary, and the marine estuary (Table 2-1). In particular, we installed two receivers in the main channel adjacent to Cock Robin Island near the upper terminus of the estuary to ensure detection of any tagged green sturgeon entering the river above the estuary, which would be behavior consistent with spawning migration. The marine estuary receiver was placed 1 km straight off of the mouth of the Eel River in the Pacific Ocean. The locations of receivers not in the estuary included the first pool above the South Fork in the mainstem (rkm 65.5) and the 12^{th} Street Hole in Fortuna (rkm 20). Receivers in the river and riverine portion of the estuary were anchored with weights and attached to black PVC coated galvanized cable that was secured to rock using a rock hammer drill and bolts or by wrapping the cable around a boulder or tree. We deployed receivers in later March or early April with periodic downloading and retrieval after the first fall freshets but before winter high water. This ensures detection of outmigrating sturgeon as results from the Klamath River have consistently shown that tagged adult green sturgeon often outmigrate during the first fall freshets but are not likely to be migrating in the river during the winter (McCovey 2011, Dr. Joshua Strange, Fish Biologist, Sweet River Sciences). Further, the high turbidity associated with winter flow events tends to greatly decrease the detection range of sonic receivers and exposes them to mechanical damage from debris and abrasion.

Table 2-1. Location and years of deployment of receivers to detect adult green sturgeon tagged with acoustic tracking tags.

Year(s)	Location	Coordinates	rkm
2014	Ocean, Eel River mouth	40.64654, -124.32578	-1.0
2014–2016	Cock Robin Island Bridge, southern	40.63609, -124.28168	2.0
2014–2016	Cock Robin Island Bridge, northern	40.63694, -124.28212	2.0
2014	Upper estuary, north arm	40.62932, -124.27433	3.0
2014	Upper estuary, south arm	40.61752, -124.28557	2.5
2015, 2016	12th Street pool, Fortuna	40.57839, -124.15547	19.0
2015, 2016	Mainstem above South Fork Eel	40.35445, -123.91419	65.0

In addition to the receivers within the river, we deployed one receiver off of the mouth of the Eel River in the marine portion of the estuary in the nearshore Pacific Ocean. This receiver was anchored to the bottom and floated near the surface with specialized rigging developed for this purpose (Figure 2-4), similar to the Pacific Ocean Shelf Tracking Project (POST) array concept.

Figure 2-4. Rigging system used to deploy the marine acoustic receiver off of the mouth of the Eel River.

2.3 Population of Origin

Determination of population of origin was achieved by genetic analysis of tissue samples obtained during capture of adults for acoustic tagging. As part of the tagging procedure, we clipped off a fingernail size piece of rayed fin (either anal or dorsal fin), which was divided into two equal size pieces placed into labeled epitubes with 90% ethanol for preservation. These samples were then shipped to Dr. Carlos Garza of the NOAA Southwest Fisheries Science Center. The genetic analysis techniques used by Dr. Garza's lab to identify the population of origin of green sturgeon (NDPS vs. SDPS) are reported by Anderson et al. (2017).

2.4 Experimental Helicopter Survey

In July of 2014, we conducted an experimental low-elevation helicopter aerial survey of the study area utilizing an in-kind contribution of a CDFW pilot and helicopter. The section of river surveyed by helicopter was from the confluence of the Van Duzen River to the vicinity of Cape Horn Dam. Our primary aim was to test the ability to spot adult sturgeon in pools from the air in the Eel River, however, even under low flow conditions and relatively clear water visibility, the bottom was obscured in pools greater than ~7 m in depth making it impossible to see any adult sturgeon holding in the bottom of deeper pools. The bottom was plainly visible in areas of the river shallower than this depth and any adult sturgeon would have been readily spotted. We were able to test and eliminate aerial surveys as an appropriate method for finding adult sturgeon in the Eel River. However, the aerial survey provided a valuable general assessment of habitat quality and confirmed that any adult sturgeon over-summering in the Eel River would only be found in the deeper pools, consistent with our sonar survey protocols and the findings from sturgeon studies in the Klamath River. This survey also allowed for visual assessment of pools and their distribution, general habitat quality, and confirmed the inability of adult sturgeon to move between pools under low flow conditions in a drought year due to the extreme shallowness of riffles observed.

3 RESULTS

3.1 Sonar Surveys

3.1.1 Spring survey 2014

We conducted our first spring survey from 9 to 15 April 2014, during the last possible window for navigation of the mainstem Eel River. The survey was conducted during the descending limb of the last high flow event of the water year at moderately low flows of approximately 2,000 to 4,000 cfs at the Scotia USGS gauge (rkm 36) (Figure 3-1). Drought conditions prevailed during the 2014 water year, with very little rain and with exceptionally low flows until February.

During the 2014 spring survey, we inspected 95 meso-habitat units over 192 km for the presence of green sturgeon from Dos Rios to the estuary. These units ranged from 7 ft (2 m) deep to 45 ft (14 m) deep; all but 17 units were greater than 5 m (16 ft) deep, given our initial target criteria of sampling meso-habitat units ≥ 5 m deep. The number of units by depth category is shown in Table 3-1 for the lower main Eel sub-basin and the middle main Eel sub-basin as surveyed in 2014. The full list of units surveyed for all study years and their depths and locations is reported in Appendix A. The locations of those units are also overlaid onto aerial imagery in Appendix B.

Table 3-1. Number of meso-habitat units by depth category and sub-basin as surveyed during the 2014 spring survey.

Depth range (m)	Ocean (rkm 0) to South Fork Eel (rkm 65)		South Fork Eel (rkm 65) to Dos Rios (rkm 192)	
	Units	Sturgeon	Units	Sturgeon
2–4.9 m	4	1	13	1
5–9.9 m	10	0	51	0
>10 m	2	0	1	0

Our observations in 2014 indicated that many locations within the study area had the fluvial features, hydraulics, and depth documented to provide suitable green sturgeon holding areas in other spawning rivers. Simply stated, many pools and deep runs surveyed in the Eel River appeared physically suitable for green sturgeon spawning and holding.

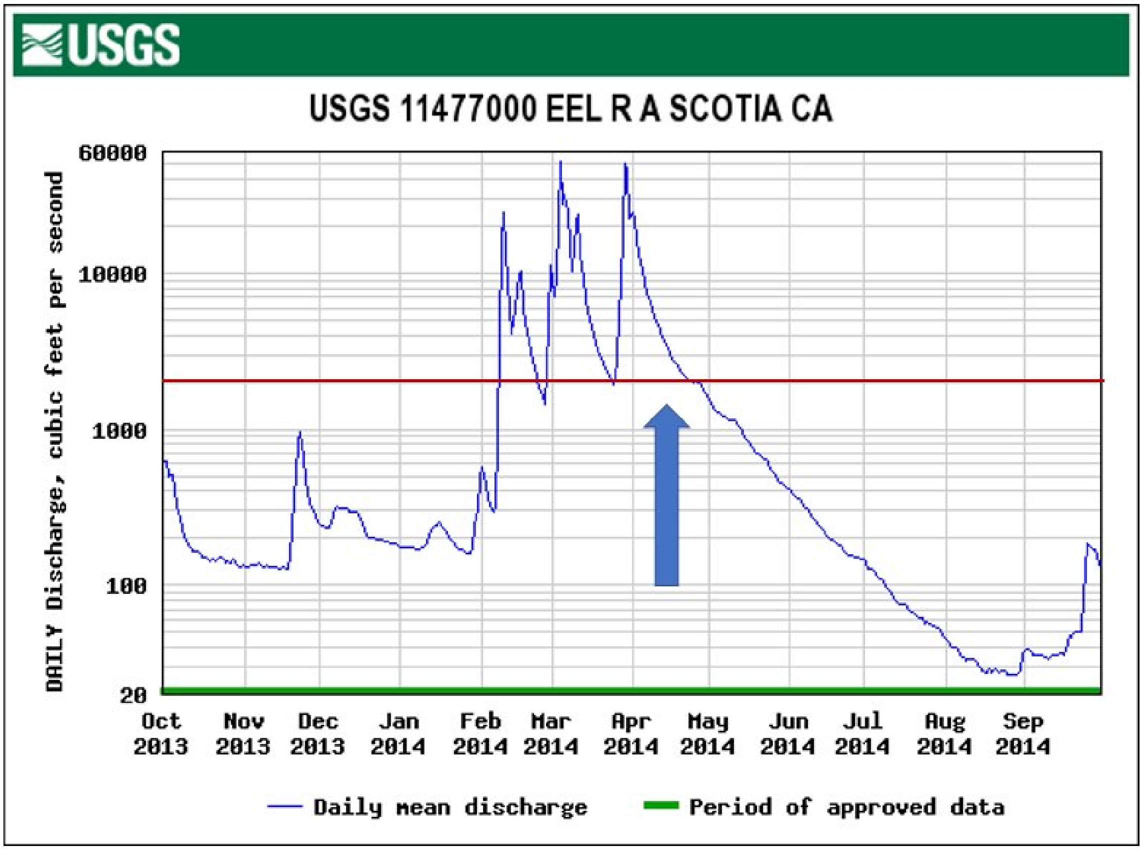

Figure 3-1. Flows on the lower mainstem Eel River at Scotia (rkm 36) during the dry water year of 2014. The blue arrow indicates the timing of the spring survey and the red line indicates flows below which navigation of the survey reach becomes impossible and upstream migration of adult sturgeon to spawning grounds may be limited.

However, a major difference apparent in the Eel River as opposed to other spawning rivers is the much higher level of turbidity and a greater predominance of finer grained substrate, as was clearly visible on the DIDSON imagery. In the Rogue, Klamath and Sacramento rivers, green sturgeon occupy locations with mostly gravel and cobble substrates intermixed within a bedrock and boulder border, which is considered ideal for spawning, egg retention, and embroyo survival. Most locations we surveyed had fine grained substrates comprised of silt, sand, and small gravels based on visual observations and sonar images. Very few locations contained coarse grained and cobble substrates. However, we did not perform any direct measurements of substrate composition such as video camera analysis or bulk sampling.

During the course of the 2014 spring survey, three sturgeon or sturgeon-shaped objects were observed. The first possible sturgeon was detected via sonar in a 30 ft (9 m) deep pool at rkm 147. However, this was only a single observation of a sturgeon-shaped object that did not change position with respect to the bottom, showed no tail beat pattern, and was not accompanied by another sturgeon. The second potential sturgeon was detected via the DIDSON in a 12 ft (3.5 m) deep run (unit 77) at rkm 67. This detection was of a sturgeon-shaped object that moved quickly through the DIDSON viewing screen in an upstream direction. This detection was not accompanied by another sturgeon. Given the type of habitat where the observation occurred, rapid upstream movement, and location within the study area, we hypothesize that this was an actively migrating adult sturgeon. In fact, we sampled this shallower unit because, after detecting only one sturgeon in deep water habitat upstream, we theorized that any adult sturgeon present in the study area were still actively migrating to spawning and holding pools. The third detection of an adult green sturgeon occurred when we visually observed of a 2-m long individual adult swimming upstream in a 2 ft (0.6 m) deep riffle between units 92 and 93 at rkm 9.5 just upstream of tidewater.

In summary, depending on the threshold of certainty, we detected between one and three adult sturgeon in the mainstem Eel River from Dos Rios to the estuary during the Year 1 spring sonar survey. We believe that we did observe two true adult sturgeon but are not confident that the third was actually a sturgeon. We detected a single sturgeon in three of 95 meso-habitat units resulting in a native occupancy rate of 3.16%. Since we only detected individual sturgeon, we will assume the number of occupied habitat units to be equal to the number of detected sturgeon. Thus, depending on the interpretation of certainty in the number of sturgeon detected during the survey and hypothetical detection probability, we estimate that between one and six habitat units were occupied by a single sturgeon in the Eel River study area during our sample period. It should be noted that if green sturgeon were indeed actively migrating in April as we hypothesize, then we would have missed an unknown but significant portion of fish that were moving through shallow habitat units or had not yet entered the river system from the ocean. Also, while we did survey the estuary, we were not able to do so comprehensively due to its size and weather constraints and may have missed additional fish there.

3.1.2 Supplemental summer survey 2014

During August 2014, we surveyed five of the largest and deepest pools in the lower mainstem Eel River for adult green sturgeon. The pools surveyed (from upstream to downstream) were located at Fort Seward, South Fork Eel confluence, High Rock, Holmes, and Rio Dell (Table 3-2). No detections of adult sturgeon occurred during this survey.

Table 3-2. Mobile sonar survey results from the summer of 2015. Unit # corresponds to those in Appendix B.

Unit #	Location	Sturgeon	Max depth (m)	RKM
153/154	Rio Dell	0	7.3	32
139/140	Holmes	0	9.1	55
135	High Rock	0	10.4	62
131/132	SF Confluence	0	4.0	65
96 & 97/98	Fort Seward	0	9.2	102
Total		**0**		

3.1.3 Spring survey 2015

Due to the second consecutive year of severe drought, low flow conditions on the mainstem Eel River precluded navigation during the spring green sturgeon migratory period. Flows dropped below 2,000 cfs, the level safely navigable by the survey vessel, by mid-March 2015 (Figure 3-2). Therefore, no spring surveys were performed in 2015.

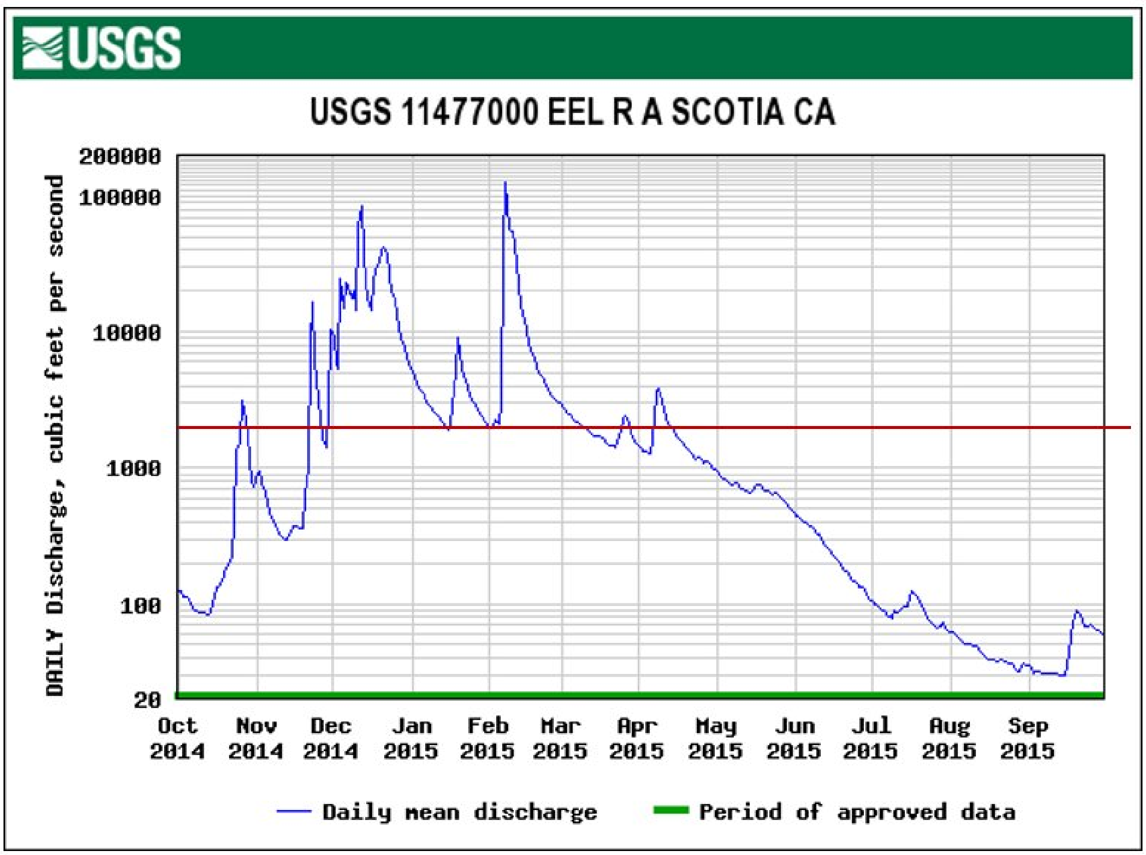

Figure 3-2. Flows on the lower mainstem Eel River at Scotia (rkm 36) during the dry water year of 2015. No spring survey occurred as flows were already too low for navigation by the start of the sturgeon migration season. The red line indicates flows below which navigation of the survey reach becomes impossible and upstream migration of adult sturgeon to spawning grounds may become problematic.

3.1.4 Supplemental summer survey 2015

During late August 2015, we surveyed eight pools in the lower mainstem Eel River for adult green sturgeon with the mobile DIDSON sonar. These pools represented the largest and deepest pools that were accessible in the lower 65 km of the mainstem from the confluence of the South Fork Eel to the estuary. We estimated a total of 7–12 adult sturgeon, depending on level of certainty in each detection (Table 3-3). Based on our perceived certainty in potential detections, we believe the true number of observed adults during this survey was closer to 12 than to 7.

Table 3-3. Mobile sonar survey results from the summer of 2015. Unit # corresponds to those in Appendix B. The number of sturgeon is an estimate with a range based on the level of certainty of observations.

Unit #	Location	Sturgeon	Max depth (m)	rkm
157	12th Street	2	4.9	19
155	Price Creek	0	4.6	23
153/154	Rio Dell	1–3	7.3	32
148	Stafford	0	5.5	42
147	Jordan Creek	2	7.9	45
139/140	Holmes	2	9.1	55
135	High Rock	0–3	10.4	62
131/132	SF Confluence	0	4.0	65
Total		**7–12**		

3.1.5 Spring survey 2016

In 2016, we conducted our spring survey from 3–10 May 2016 during the descending limb of the wet season hydrograph and the last possible window for navigation of the mainstem Eel River (Figure 3-3). Stream flows during the survey were moderate to low, ranging from approximately 1,500 to 3,000 cfs at the Scotia USGS gauge. Drought conditions finally lessened in 2016 and the water year was closer to average.

During the spring 2016 mobile sonar survey, we inspected 115 meso-habitat units for the presence of green sturgeon over the 192 km from Dos Rios to the estuary. These units ranged from 8 ft (2.5 m) deep to 45 ft (14 m) deep, but the vast majority of units were ≥ 5 m in depth (Table 3-4). Overall, 41 units were ≥ 6 m in depth, 17 units were ≥ 7.5 m in depth, 8 units were ≥ 9 m in depth, and 2 units were ≥ 12 m in depth.

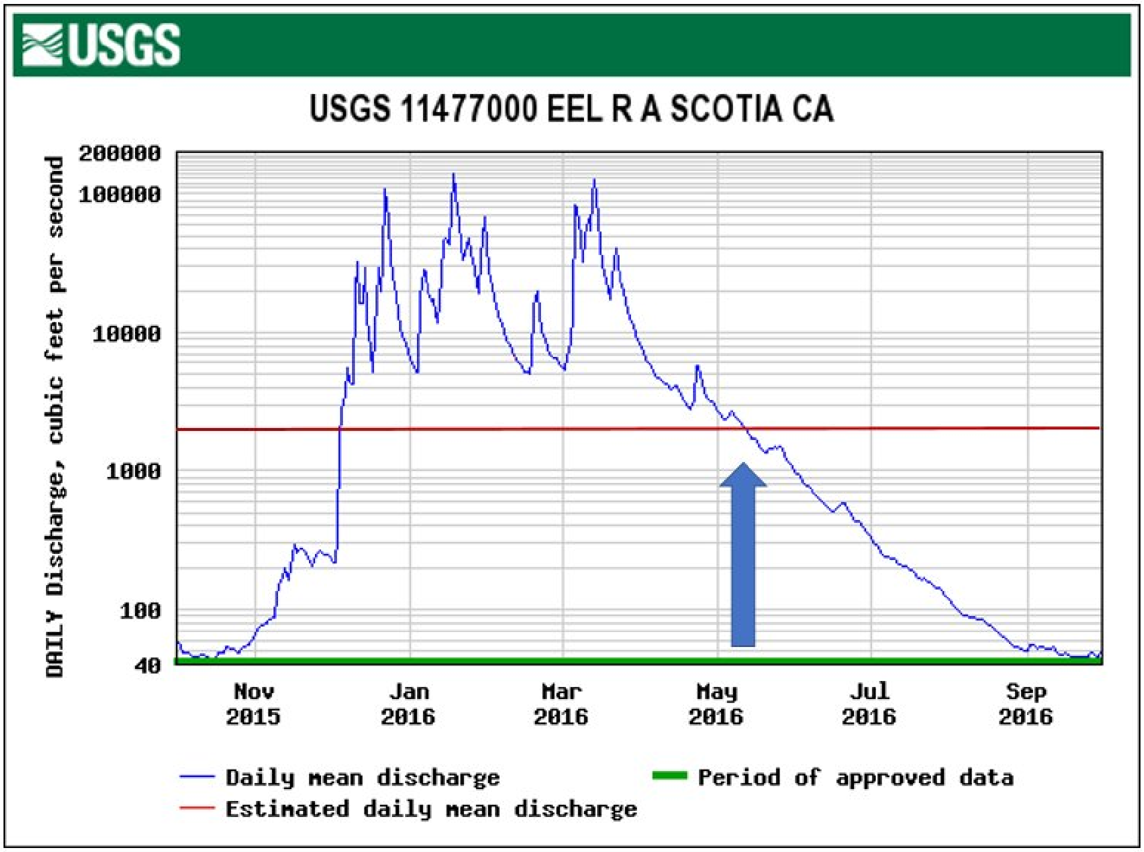

Figure 3-3. Flows on the lower mainstem Eel River at Scotia (rkm 36) during the normal water year of 2016. The blue arrow indicates the timing of the spring survey and the red line indicates flows below which navigation of the survey reach becomes impossible and upstream migration of adult sturgeon to spawning grounds may become problematic.

Table 3-4. Number of meso-habitat units by depth category and sub-basin as surveyed during the 2016 spring survey.

Depth range (m)	Ocean (rkm 0) to South Fork Eel (rkm 65)		South Fork Eel (rkm 65) to Dos Rios (rkm 192)	
	Units	Sturgeon	Units	Sturgeon
2–4.9 m	6	2	44	0
5–9.9 m	8	0	48	3
>10 m	2	0	2	6

In sum, depending on the threshold of certainty and detection probability applied, we detected a minimum of 11 adult sturgeon in the Eel River study area during spring 2016 surveys. Most of these fish (n=6) were observed holding in the deepest pool in the study area in the vicinity of Island Mountain, which was also the furthest upstream of all adult sturgeon sightings at rkm ~ 140 (Figure 3-4). This pool was noted during the 2014 spring survey as being potentially the best sturgeon spawning and holding pool in the study area, but no fish were observed there in that year, likely due to low flows associated with the drought. Another 3 adult sturgeon were observed holding in a small but deep pool (6.7 m) in the vicinity of Fort Seward (rkm 100), but surprisingly, no fish were observed holding in two notably larger and deeper pools upstream of Fort Seward. The remaining two adult sturgeon observed during the spring 2016 survey were seen visually from the boat and appeared to be actively migrating. These two fish were observed at separate locations below the South Fork Eel confluence in the vicinity of Pepperwood (rkm 50).

Given that some fish were still actively migrating, our minimum estimate of 11 adult sturgeon is likely an underestimation. Also, while we did survey the estuary, we were not able to do so comprehensively due to its size and time constraints and may have missed additional fish; although we can rule out any large concentrations of adult sturgeon in the main pools of the estuary.

Figure 3-4. Major green sturgeon congregation pool with excellent spawning habitat characteristics in the vicinity of Island Mountain.

3.1.6 Supplemental summer survey 2016

During August 2016, we repeated our survey of the eight pools in the lower mainstem Eel River for adult green sturgeon with mobile DIDSON sonar as occurred in 2015. These pools represented the most notable larger and deeper pools in the lower 65 km of the mainstem from the confluence of the South Fork Eel to the estuary. We detected an estimated total of 1 to 4 adult sturgeon (Table 3-5). Based on observations and subsequent tagging efforts, we believe the true number of observed adults during this survey was closer to 1 than to 4.

Table 3-5. Mobile sonar survey results from the summer of 2016. Unit # corresponds to those in Appendix B. The number of sturgeon is an estimate with a range based on the level of certainty of observations.

Unit #	Location	Sturgeon	Max. depth (m)	rkm
157	12th Street	0	4.9	19
155	Price Creek	0	4.6	23
153/154	Rio Dell	0	7.3	32
148	Stafford	0	5.5	42
147	Jordan Creek	1	7.9	45
139/140	Holmes	0–3	9.1	55
135	High Rock	0	10.4	62
131/132	SF Confluence	0	4.0	65
Total		**1–4**		

3.2 Acoustic Biotelemetry

3.2.1 Acoustic tagging

We captured and tagged five adult green sturgeon in May and August of 2015, including two males, one female, and two fish of unknown sex. Fish tagged in the spring had ripe gonads, whereas fish tagged in the summer had only remnants or a complete absence of gonads. The dates, locations, sizes, sexes, and tag codes for these five fish are reported in Table 3-6. Acoustic receiver detection data for these fish are presented below. No fish were captured or tagged during limited fishing in the summer of 2016.

Table 3-6. Tagging and biological information for fish tagged in the Eel River.

Fish #	Tagging date	Tagging location	Vemco tag ID	Gonadal status	Sex	Total length (cm)	Weight (kg)	Scute count
1	4/29/2015	estuary	ID24374	ripe	M	173	34.5	25L, 26R
2	5/20/2015	~rkm 20	ID24372	ripe	M	188	31.4	26L, 25R
3	5/20/2015	~rkm 20	ID24376	remnants	F	198	29.4	25L, 28R
4	8/28/2015	~rkm 30	ID24371	post-spawn	?	164	22.4	25L, 26R
5	8/28/2015	~rkm 30	ID24373	post-spawn	?	206	33.7	26L, 27R

3.2.2 Receiver array

The locations and periods of deployment of acoustic VR2W receivers are summarized in Table 2-1. The acoustic receivers were deployed in the early spring and retrieved after the first freshets of the fall or winter, with the exception of the ocean receiver, which was deployed year-round. The ocean receiver was deployed in the early summer of 2014 and downloaded in the fall of 2014, but was lost in the fall of 2015 prior to another downloading. A new receiver was not deployed for 2016 thus detection data in the marine portion of the estuary are only available for the summer of 2014.

During the period that acoustic receivers were deployed, no sturgeon tagged in other river basins and locations were detected entering into the Eel River or its estuary above rkm 2. We are confident that the 1 km detection range and duration of deployment was sufficient to have detected any tagged sturgeon that entered the Eel River above Cock Robin Island at rkm 2.

However, 21 sturgeon tagged in other locations were detected by the ocean receiver in the marine portion of the estuary. These fish represented both Northern and Southern DPS fish and were tagged in the Sacramento River, San Pablo Bay, Willapa Bay, Rogue River, and the Columbia River. We provided detection data to the respective researchers from the sturgeon they tagged. Our ocean receiver also detected numerous white sharks tagged by researchers from Stanford University, providing valuable data on this species' movement timing and distribution.

In 2015, we successfully tagged several adult green sturgeon in the Eel River and these were detected in our receiver array. All five tagged sturgeon remained in the pools they were tagged in from the time of tagging (May or August 2015) until the first significant freshet of the wet season during the first week of December 2015, at which time they were detected outmigrating to the ocean in clustered grouping (Table 3-7). Figure 3-5 shows their outmigration timing, from 4–7 December 2015, in relation to river flow, and indicates that the first fish outmigrated as flow rose rapidly and exceeded 1,500 cfs at Scotia and the last fish outmigrated three days later at a flow of 5,000 cfs.

Table 3-7. Outmigration timing of fish tagged in the Eel River based on date and time of last detection at the acoustic receivers at Fortuna (rkm 20) and Cock Robin Island (rkm 2).

Tagging date	Vemco tag ID	Fortuna		Cock Robin Island	
		Outmigration date	Time	Outmigration date	Time
4/29/2015	ID24374	unknown		unknown	
5/20/2015	ID24372	12/4/2015	14:28	12/6/2015	8:26
5/20/2015	ID24376	12/4/2015	11:04	12/5/2015	17:01
8/28/2015	ID24371	12/5/2015	16:52	12/6/2015	7:05
8/28/2015	ID24373	12/7/2015	13:26	12/8/2015	20:08

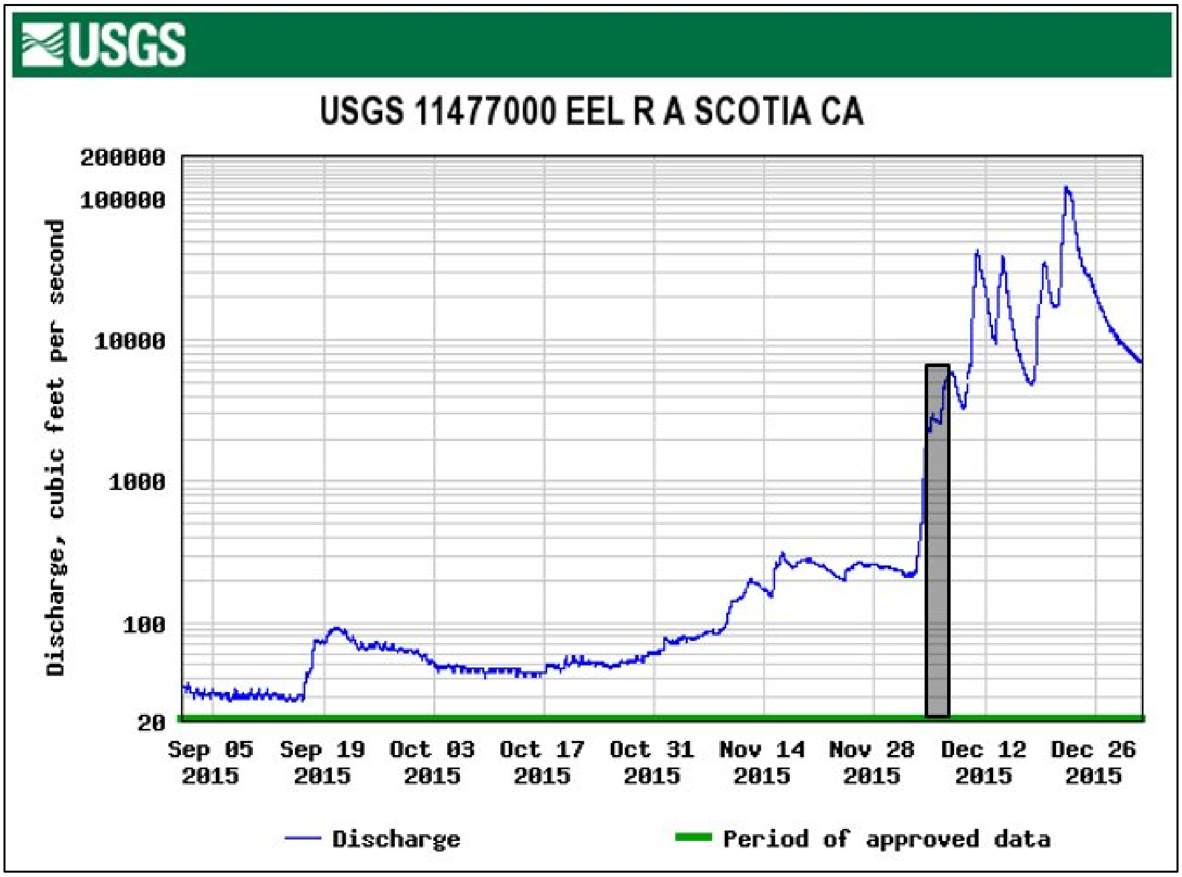

Figure 3-5. Stream flow (cfs) on the lower mainstem Eel River at Scotia (rkm 36) during the fall of 2015 in relation to outmigration of the adult green sturgeon tagged in the river during the spring and summer (grey bar).

3.3 Population of Origin

We collected tissue samples from all five green sturgeon tagged in 2015. Genetic testing of these samples by Dr. Garza's lab at the NMFS Santa Cruz facility determined conclusively that all adult sturgeon tagged thus far in the Eel River (five in 2015) were Northern DPS in origin.

4 DISCUSSION

4.1 Major Findings, Conclusions, and Hypotheses

Results of this study indicate that a spawning run of green sturgeon still occurs in the Eel River basin annually. This conclusion is based on observations of adults in the river in each year of the study, ripe gonads in fish tagged in the spring, presence of post-spawning during summer tagging, actively migrating adults in the spring, and adult green sturgeon over-summering as far as 140 km upriver—all of which are consistent with a spawning run. While the size of the spawning run in Eel River basin and the degree of spawning success remain unknown, the Eel River can be added to the official list of spawning rivers used by green sturgeon, along with the Klamath, Rogue, and Sacramento rivers. This finding is significant and encouraging given the small number of documented spawning rivers and populations for green sturgeon, and given the fact that the species was considered extirpated from the Eel River basin (Moyle 2002, NMFS 2010).

Notably, no green sturgeon tagged in other river systems entered the Eel River during the study years, even though over 20 individuals tagged in other locations, including from both DPSs, were detected in the ocean within 2 km of the mouth of the Eel River. This finding suggests two hypotheses: (1) the riverine portion of the Eel River estuary is likely not used as a preferred feeding habitat for adult sturgeon, otherwise some of those fish would have entered to feed; and (2) there is a preponderance of spawning river fidelity for green sturgeon and the possibility of an Eel River specific sub-population. Additional years of monitoring data will likely refute or support these hypotheses. In regard to the first hypothesis, the riverine portion of the Klamath River estuary was also not used by adult sturgeon tagged in other locations that were detected in the marine portion of the estuary off of the mouth of the Klamath River (McCovey 2011). In regard to the second, the hypothesis of a distinct Eel River subpopulation is consistent with genetic and tagging studies that revealed limited mixing between spawners in the Klamath and Rogue rivers (Lindley et al. 2011). Also a more recent finding of a Northern DPS fish captured in the Columbia River estuary could not be assigned to either the Rogue or Klamath river (Schreier et al. 2016), supporting a previous genetic analyses that suggested an unidentified sub-population in the Northern DPS (Israel et al. 2004).

In terms of genetic population structure, 100% of adult green sturgeon captured in the Eel River were of Northern DPS origin (*n*=5). This sample size is too small to completely rule out the potential that some Southern DPSs fish also spawn in the Eel River, but we consider that unlikely based on our hypothesis of a distinct Eel River sub-population and supporting evidence to date.

Also, studies in the Klamath and Rogue rivers have not documented mixing of Southern DPS fish in those spawning runs (Benson et al. 2007, McCovey 2011, Lindley et al. 2011), which leads to the prediction that this would also hold true for the Eel River. Further tagging and genetic analysis of additional tissue samples from green sturgeon in the Eel River will provide an answer, especially if from juvenile fish captured in the Eel River.

The possibility of a distinct Eel River sub-population of green sturgeon highlights the potential for sub-population-specific adaptions, in particular spawning and run-timing. Compared with the Rogue and Klamath rivers, the Eel River has less snowmelt and an earlier onset of low flow conditions in the late spring, which contribute to warmer water temperatures (Figure 4-1).

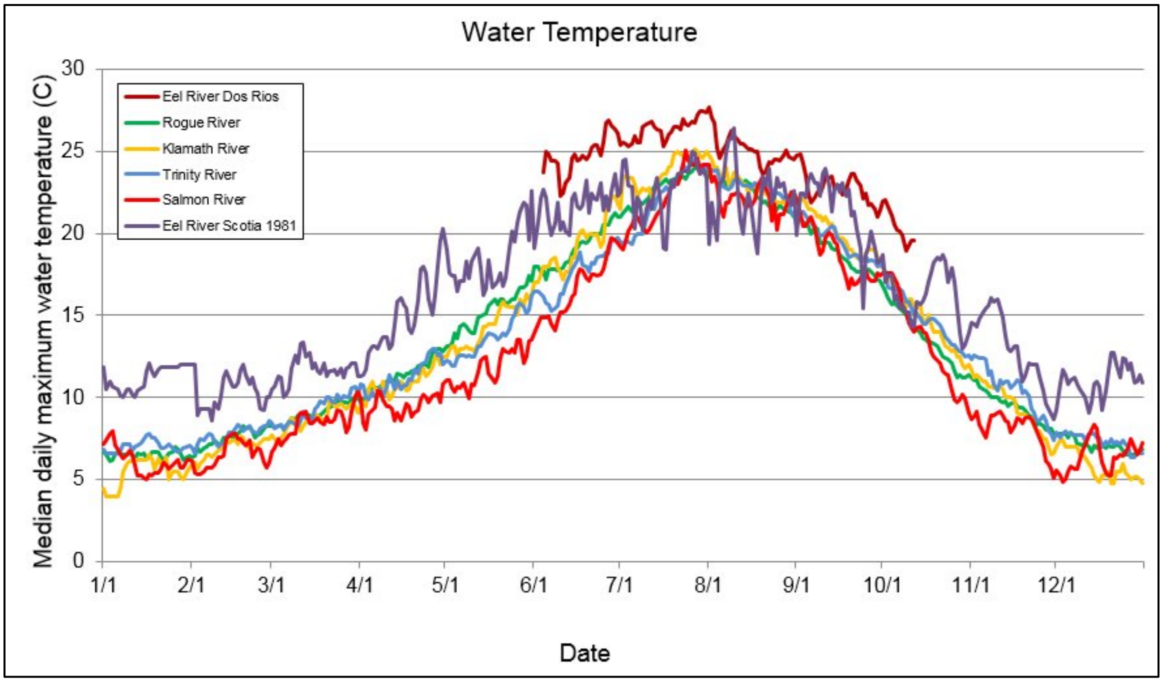

Figure 4-1. Water temperature in the Eel River in an example year versus medians in the Rogue River and the Klamath River and its primary tributaries (Trinity and Salmon rivers), to illustrate the substantially earlier onset of low flow and warmer conditions in the Eel River.

It is well documented that summer low flows preclude green sturgeon from returning to the ocean after spawning and result in over-summer holding in or near spawning pools (Benson et al. 2007, Erickson and Webb 2007, McCovey 2011). The low flows that inhibit adult green sturgeon from returning to the ocean immediately after spawning could also block their ability to migrate upstream to spawning pools. Given these circumstances, we hypothesized that green sturgeon in the Eel River would migrate earlier on average than their counterparts in the Klamath and Rogue rivers. The severe drought conditions of 2014 provided a test of this hypothesis, and yet counter to its prediction, we only documented fish actively migrating in the lower river with no confirmed adults in historical upriver (around rkm 100) spawning areas during our survey in mid-April, after which flows became exceedingly low for that time of year. This dynamic was observed again in the drought year of 2015, which also included documentation of adults over-summering and apparently spawning in the lower mainstem as far downstream as Fortuna at rkm 20. However, with the return of more normal precipitation and hydrologic conditions in 2016, the majority of adult sturgeon detected were located in their historical spawning areas approximately 100–140 km upriver, with few individuals observed actively migrating, and in the summer only one individual was observed holding in the lower mainstem. Based on these findings, we now hypothesize that run timing for green sturgeon is under genetic control and adapted to long-term average environmental conditions, as is true for conspecific anadromous salmonids (Quinn et al. 2002). To the extent that Eel River green sturgeon are a distinct population, there is still the potential that they do have a slightly earlier run-timing than sturgeon in the Klamath and Rouge rivers, with the latter two peaking in May but also running well into June.

The hypothesis of a static run-timing and fish spawning in the lower mainstem Eel River, downstream of reaches with preferred habitat, during dry years has important conservation implications. While this migration and spawning strategy likely still allows spawning in drought years, essentially making the best of a bad situation, the spawning success of adults forced to spawn in the lower river and the recruitment success of their progeny are unknown. Green sturgeon prefer to broadcast their eggs over cobble and large gravel spawning substrates that contain ample interstitial spaces to provide protection and also water flow for adequate dissolved oxygen delivery to developing embryos. The Eel River is listed under the Clean Water Act for fine sediment and temperature impairments (EPA 2007), thus the quality of spawning habitats for green sturgeon is likely reduced throughout their distribution due to increased embeddedness with fine sediments and decreased interstitial spaces. Temperature and sediment impairments are listed as threats to any remaining green sturgeon in the Eel River (Doukakis 2014). High fine sediment loads can serve to reduce the growth and survival of juvenile salmonids (Suttle et al. 2004). Like juvenile salmonids, young-of-the-year (YOY) green sturgeon larvae and fry eat benthic macro-invertebrates and as such would likely also experience reduced growth and survival as a result of fine sediment impairment impacts to benthic-invertebrate production. In addition to sediment impairments, thermal impairments can cause starvation mortality to newly-emerged juvenile sturgeon due to earlier onset of high water temperatures resulting in a bioenergetic deficit (i.e., more energy expended then obtained from food) during the sensitive early life-history window after hatching, depending on the level of food available and dissolved oxygen concentrations (Allen et al. 2006, Lee et al. 2016). During the 2016 spring survey, instantaneous measurements of water temperature ranged from 15 to 18°C, which was already approaching or exceeding optimal levels for YOY growth and survival.

In general, the lower mainstem Eel River (below the South Fork at rkm 65) has distinctly smaller substrates, lower sheer stress hydraulic forces, greater fine sediment impacts, and shallower pools compared with upstream mainstem reaches. These differences can be readily seen in a visual comparison of an apparent spawning pool used in the lower river (near rkm 20) in 2015 versus in the middle river in 2016 (near rkm 140) (Figure 4-2). Therefore, we hypothesize that spawning success is greater in the upper reaches (e.g., rkm 75 to 155) due to greater quantity and quality of preferred spawning substrates and holding habitats, and thus is the preferred spawning reach for green sturgeon in the Eel River. This hypothesis is consistent with the regular catches of YOY juvenile green sturgeon in these upriver areas (two sites at rkm 75 and 100) in May, June, and July but not in the lower river (two sites at rkm 32 and 55) during fisheries emigrant trapping conducted by the CDFW during the late 1960s (Puckett 1976).

Importantly, green sturgeon do not currently appear to enter the Eel River earlier in drought years to compensate for a truncated spring hydrograph in order to reach preferred spawning areas before flows become too low. We predict that with continued climate change and increasingly earlier onset of low flow conditions, the lower mainstem Eel River will be increasingly important as green sturgeon spawning and holding habitat, and earlier spawning may also be under positive selection pressure. Primary vulnerabilities for adults using the lower mainstem are related to post-spawn holding stress to adults due to warm water temperatures, greater vulnerability to potential poachers, and possible starvation mortality to newly-emerged YOY sturgeon due to fine sediment impairments during this sensitive part of the life cycle.

Figure 4-2. Comparison of pools used for holding and presumably also for spawning in the lower river in Fortuna (rkm ~20) during the dry water year of 2015 (top) versus one in the middle river near Island Mountain (rkm ~140) during the normal water year of 2016 (bottom). Note the finer substrate, lack of coarse substrate, and shallower depth for the pool in the lower river. Image source: Google Earth.

If earlier onset of summer low flow conditions continues to accelerate due to reduced snowpack and more severe droughts associated with climate change, and green sturgeon adults are more frequently prevented from reaching preferred spawning areas, then management measures such as pulsed-flow releases from the hydroelectric reservoirs on the mainstem Eel River timed to coincide with the peak migration period could be evaluated to determine if they facilitate migration to preferred spawning areas. Detections of adults outmigrating through the lower Eel

River in 2015 suggest a potential minimum flow threshold for adult green sturgeon outmigration of approximately 1,500 to 2,000 cfs at Scotia. However, it is unclear whether this flow also represents the minimum level necessary for passage over riffles during upstream migration. Additional biotelemetry data would provide a means to infer the mechanism associated with flows that trigger outmigration and also to test the hypothesis that 1,500 cfs to 2,000 cfs is the minimum flow level needed for upstream migration over shallow riffles. Based on observations on the Klamath River, turbidity, depth, and perceived predation risk may play a role in when adult green sturgeon decide to outmigrate in relation to flows (Dr. Joshua Strange, Sweet River Sciences, pers. obs.). Changes to the magnitude and/or timing of flow releases from upstream reservoirs may be important components of management measures in the future to compensate for drought and earlier onset of summer conditions and improve spawning success and population viability of green sturgeon in the Eel River.

As has been found in the Klamath and Rogue rivers (Erikson et al. 2007, McCovey 2011), adult green sturgeon in the Eel River generally over-summer in deep pools after spawning and outmigrate with the first freshet of the wet season in the fall or early winter. In wetter years, a greater proportion of fish migrate further up the Rogue and in the Klamath and a greater proportion are able to return to the ocean after spawning in the spring and thereby avoid over-summering in the river. Anecdotally, the green sturgeon run also appears to be larger in wetter years in the Klamath River (Dr. Joshua Strange, Sweet River Sciences, pers. obs.). Presumably sturgeon are cueing in on the more favorable spawning and rearing conditions in those years. We predict these same dynamics in the Eel River in wet years, which may be enabled by the variable spawning periodicity of green sturgeon, which do not need to spawn every year. Given the record wet year in 2017 and associated high spring flows, our planned 2017 spring sonar survey will help test of this hypothesis.

Physical habitat in the Eel River is suitable for sturgeon spawning and post-spawn holding in terms of pools of sufficient depth, seclusion from humans, and distribution, but the amount of fine substrate and embedded substrate in pool-tailouts could significantly reduce reproductive success. Seclusion from humans is hypothesized to be a factor in why some notably deep pools in the Klamath River are not used for holding and spawning while other similar pools are (Dr. Joshua Strange, Fish Biologist, Sweet River Sciences). Aside from overly embedded substrate and truncated spring hydrographs, earlier onset of elevated water temperatures could also reduce reproductive success due to losses of juveniles soon hatching. The large estuary of the Eel River appears to provide excellent feeding and rearing opportunities for juvenile green sturgeon. Habitat restoration such as that for improved salmon rearing in the stream-estuary ecotone would likely benefit sturgeon as well, especially restoring access to estuarine sloughs and channels. The topics of reproductive success and larval recruitment and early life-history survival need further research for green sturgeon in general, including in the Eel River. To address this data gap, future studies may include juvenile sampling using riverine trawl nets as have been used on the Sacramento River (Gruber et al. 2017).

We will continue efforts to study green sturgeon in the Eel River, including conducting additional spring sonar surveys. If these surveys or other means of enumerating the size of the annual spawning run continue consecutively for the next 3 to 5 years, then we can estimate the total number of spawning adults in the sub-population. The combined data would also help with the development of a reliable long-term data set for the Eel River and thereby elucidate management and conservation strategies for green sturgeon, in both Eel River and throughout its range. This and additional recommendations for further study and study improvements are discussed in the following section.

4.2 Recommendations for Further Study and Modifications

The following is a list of major recommendations for further study of green sturgeon in the Eel River that would provide significant scientific and management value:

- Secure additional funding to allow continued research and monitoring of this important, newly-documented extant spawning run.
- Continue spring sonar surveys to enumerate the annual spawning run and describe distribution, and eventually allow for estimation of the total adult population size.
- In lieu of, or complementary to, the mobile sonar surveys, pursue a stationary sonar counting station (i.e., DIDSON or second-generation ARIS located at a favorable site near Scotia) to be operated during the spring spawning migration season to enumerate the annual spawning run and eventually allow for estimation of the total adult population size. This could be operated from April to June only (depending on flows and water year), which would reduce the costs of operation and data processing (in addition to using background subtraction software to automate post-processing of data files) and also reduce the risk of high flow issues. We have identified an excellent site between the South Fork Eel and Van Duzen rivers that has many favorable attributes and would likely only require one unit to provide full cross sectional coverage of the river channel. This same unit could then be used to conduct a mobile summer survey to enumerate the number of adults below the fixed-site sonar location and to monitor notable spawning congregations to determine the over-summer survival of adults.
- Continue tagging adults (we currently have 5 acoustic tags left and would like to purchase more) including the targeted sampling of fish identified during the census survey. If adults are only found in inaccessible pools upriver, explore the possibility of helicopter support with a suitable inflatable boat to provide access for capture and tagging.
- Annually deploy an acoustic receiver array to determine periodicity of return spawning and track any fish tagged in other locations. Biotelemetry data from continued tagging efforts could help determine the proportion of adults that over-summer for a given water year type.
- Continue collecting tissue samples from adults for genetic population identification, which could include SCUBA-based collection of tissue samples from adults in torpid conditions when water temperatures are cold.
- Explore and test the possibility of using eDNA to determine upstream extent of distribution in the mainstem Eel River and its major sub-basins, as is being done in the Sacramento River basin (Bergman et al. 2016).
- Explore boat-based benthic trawl net sampling of YOY juveniles (e.g., Gruber et al. 2017) in late summer in likely areas based on results of spring surveys to verify reproduction and measure biometrics to evaluate growth. Collect tissue samples from juveniles for additional analyses of population genetics as these natal fish would be verified to be of true Eel River origin.
- Evaluate early life-history survival and suitability of water temperatures, flows, and substrates for egg and fry survival. Monitor river temperatures year-round at Scotia to help evaluate potential thermal impacts to early-life history.
- Explore the possibility of an experimental pulse flow from upstream reservoirs and monitor effects on adult upstream migration in a dry year.

5 LITERATURE CITED

Adams, P. B., C. B. Grimes, J. E. Hightower, S. T. Lindley, and M. C. Moser. 2002. Status review of the North American green sturgeon (*Acipenser medirostris*). National Marine Fisheries Service, Santa Cruz, California.

Adams, P. B., C. B. 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: 339–356.

Allen, P., J. Cech, Jr., A. Vlazny, S. Doroshov, J. Van Eenennaam, and D. Hillemeier. 2002. Warm water-induced growth depression in juvenile green sturgeon. Proceedings of the symposium and 36th annual meeting of the California-Nevada chapter of the American Fisheries Society, April 18–20, 2002, Tahoe City, California.

Allen, P. J., B. Hodge, I. Werner, and J. J. Cech. 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: 1,360–1,369.

Allen, P. J., J. A. Hobbs, J. J. Cech, J. P. Van Eenennaam, and S. I. Doroshov. 2009. Using trace elements in pectoral fin rays to assess life history movements in sturgeon: estimating age at initial seawater entry in Klamath River green sturgeon. Transactions of the American Fisheries Society 138: 240–250.

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: DOI 10.1007/s10592-017-0963-5.

Beamesderfer, R. C. P., G. Kopp, and D. Demko. 2004. Review of the distribution, life history, and population dynamics of green sturgeon with reference to California's Central Valley. S.P. Cramer and Associates, Oakdale, California.

Benson, R. L., S. Turo, S., and B. W. McCovey Jr. 2007. Migration and movement patterns of green sturgeon (*Acipenser medirostris*) in the Klamath and Trinity rivers, California, USA. Environmental Biology of Fishes 79: 269–279.

Bergman. P. S., G. Schumer, S. Blankenship, and E. Campbell. 2016. Detection of adult green sturgeon using environmental DNA analysis. PLoS ONE. DOI:10.1371/journal.pone.0153500.

Brown, K. 2007. Evidence of spawning by green sturgeon, *Acipenser medirostris*, in the upper Sacramento River, California. Environmental Biology of Fishes 79: 297–303.

Brown, W. M. III and J. R. Ritter. 1971. Sediment transport and turbidity in the Eel River Basin, California. Geological Survey Water-Supply Paper. 77pp.

CDFG (California Department of Fish and Game). 2002. CDFG comments to NOAA Fisheries regarding green sturgeon listing.

Deng, X., J. P. Van Eenennaam, and S. I. Doroshov. 2002. Comparison of early life stages and growth of green and white sturgeon. American Fisheries Society Symposium 28: 237–248.

Doroshov, S. I., J. P. Van Eenennaam, and J. Linares-Casenave. 2004. Biological assessment of green sturgeon in the Sacramento-San Joaquin watershed—phase 3-4; Task 2: reproduction of green sturgeon. Anadromous Fish Recovery Program Agreement #11332-1-G005.

Doukakis, P. 2014. Informal status review for the Northern Distinct Population Segment of the North American green sturgeon (*Acipenser medirostris*). Protected Resources Division, West Coast Region, NOAA Fisheries.

Gruber, J. J., W. R. Poytress, C. E. Praetorius, and D. J. Ryan. 2017. 2014 and 2015 juvenile green sturgeon capture feasibility. Technical Report. United States Fish and Wildlife Service, Red Bluff, CA. 35pp.

EPA (United States Environmental Protection Agency). 2007. Lower Eel River Total Maximum Daily Loads for Temperature and Sediment. Region 9, Water Division. San Francisco, California.

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: 255–268.

Erickson, D. L., J. A. North, J. E. Hightower, J. Weber, and L. Lauck. 2002. Movement and habitat use of green sturgeon (*Acipenser medirostris*) in the Rogue River, Oregon, USA. Journal of Applied Ichthyology 18: 565–569.

Farr, R. A., and J. C. Kern. 2005. Green sturgeon population characteristics in Oregon. Final Progress Report – Fish Research Project Oregon. Project number F-178-R. Oregon Department of Fish and Wildlife, Clackamas, Oregon.

Gaines, P. D., and C. D. Martin. 2002. Abundance and seasonal, spatial and diel distribution of juvenile salmonids passing the Red Bluff Diversion Dam, Sacramento River. USFWS final report to the U.S. Bureau of Reclamation. Red Bluff Research Pumping Plant Report Series Volume 14. Red Bluff, California.

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: 245–258.

Huff, D. D., S. T. Rankin, P. S. Rankin, and E. A. Mora. 2011. Green sturgeon physical habitat use in the coastal Pacific Ocean. PLoS ONE 6: e25156. doi10.1371/ journal.pone.0025156.

Israel, J. A., and A. P. Klimley. 2008. Life history conceptual model – North American green sturgeon (*Acipenser medirostris*). Sacramento-San Joaquin Delta Regional Ecosystem Restoration Implementation Plan.

Israel, J. A., K. J. Bando, E. C. Anderson, and B. May. 2009. Polyploid microsatellite data reveal stock complexity among estuarine North American green sturgeon (*Acipenser medirostris*). Canadian Journal of Fisheries and Aquatic Sciences 66: 1,491–1,504.

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: 922–931.

Klimley, A. P., P. J. Allen, J. A. Israel, and J. T. Kelly. 2006. The green sturgeon and its environment, past, present and future. Environmental Biology of Fishes: DOI 10.1007/s10641-006-9177-2.

Kohlhorst, D.W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. California Fish and Game 62:32–40.

Kynard, B., E. Parker, and T. Parker. 2005. Behavior of early life intervals of Klamath River green sturgeon, *Acipenser medirostris*, with notes on body color. Environmental Biology of Fishes 72: 85–97.

Kynard, B., E. Parker, and T. Parker. 2007. Dispersal characteristics, drift distance, and wintering behavior of young Kootenai River white sturgeon: a laboratory study. Final report to Idaho Department of Fish and Game, Boise, Idaho.

Lee, S. S., S. Hung, N. A. Fanque, L. Haller, C. E. Verhille, J. Zhao, and A. E. Todgham. 2016. Effects of feed restriction on the upper temperature tolerance and heat shock response in juvenile green and white sturgeon. Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology 198: 87–95.

Lindley, S. T., D. L. Erickson, M. L. Moser, G. Williams, O. P. Langness, B. W. McCovey Jr., 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 movements among estuaries. Transactions of the American Fisheries Society 140: 108–122.

Lindley, S. T., M. L. Moser, D. L. Erickson, M. Belchik, D. W. Welch, E. Rechisky, J. T. Kelly, J. C. Heublein, and A. P. Klimley. 2008. Marine migration of North American green sturgeon. Transactions of the American Fisheries Society 137: 182–194.

Mayfield, R. B., and J. J. Cech Jr. 2004. Temperature effects on green sturgeon bioenergetics. Transactions of the American Fisheries Society 113: 961–970.

Mackenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollack, L. L. Bailey, and J. E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence (1st ed.). Elsevier-Academic Press, Amsterdam.

McCovey Jr., B. W. 2008. Klamath River green sturgeon acoustic biotelemetry monitoring – FY 2007 final report. Yurok Tribal Fisheries Program, Weitchpec, California.

McCovey, B. W. Jr. 2011. Klamath River green sturgeon acoustic tagging and biotelemetry monitoring 2010. Yurok Tribal Fisheries Program, Technical Report, Weitchpec, California.

Mora, E. A., S. T. Lindley, D. L. Erickson, and A. P. Klimley. 2015. Estimating the riverine abundance of green sturgeon using a dual-frequency identification sonar. North American Journal of Fisheries Management 35: 557–566.

Moser, M. L., and S. T. Lindley. 2007. Use of Washington estuaries by subadult and adult green sturgeon. Environmental Biology of Fishes. 79: 243–253.

Moyle, P. B., P. J. Foley, and R. M. Yoshiyama. 1992. Status of green sturgeon, *Acipenser medirostris*, in California. Final Report Prepared by University of California, Davis for National Marine Fisheries Service.

Moyle, P. B. 2002. Inland fishes of California. University of California Press, Berkeley.

Nakamoto, R.J., T.T. Kisanuki, and G.H. Goldsmith. 1995. Age and growth of Klamath River green sturgeon (*Acipenser medirostris*). U.S. Fish and Wildlife Service. Project #93-FP-13.

NMFS (National Marine Fisheries Service). 2005. Green sturgeon (*Acipenser medirostris*) status review update. Southwest Fisheries Science Center, Long Beach, California.

NMFS. 2006. Endangered and threatened wildlife and plants: threatened status for Southern Distinct Population Segment of North American green sturgeon – final rule. Federal Register 71: 17,757–17,766.

NMFS. 2009a. Endangered and threatened wildlife and plants: final rulemaking to designate critical habitat for the threatened for Southern Distinct Population Segment of North American green sturgeon – final rule. Federal Register 74: 52,300–52,348.

NMFS. 2009b. Designation of critical habitat for the threatened Southern Distinct Population Segment of North American green sturgeon – final biological report. NMFS Southwest Region, Long Beach, California.

NMFS. 2010. Federal recovery outline: North American green sturgeon southern distinct population segment. Santa Rosa, California.

Poytress, W. R., J. J. Gruber, and J. P. Van Eenennaam. 2010. 2009 Upper Sacramento River green sturgeon spawning habitat and larval migration surveys. Annual Report. Prepared by U.S. Fish and Wildlife Service for U.S. Bureau of Reclamation, Red Bluff, California.

Poytress, W. R., J. J. Gruber, and J. P. Van Eenennaam. 2011. 2010 Upper Sacramento River green sturgeon spawning habitat and larval migration surveys. Annual Report. Prepared by U.S. Fish and Wildlife Service for U.S. Bureau of Reclamation, Red Bluff, California.

Puckett, L. K. 1976. Observations on the downstream migrations of anadromous fishes within the Eel River system. California Department of Fish and Game.

Quinn, T. P., J. A. Peterson, V. F. Gallucci, W. K. Hershberger, and E. L. Brannon. 2002. Artificial selection and environmental change: countervailing factors affecting the timing of spawning by coho and chinook salmon. Transactions of the American Fisheries Society 131: 591–598.

Schreier, A., O. P. Langness, J. A. Isreal, 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. Behavioral Biology of Fish: DOI 10.1007/s10641-016-0538-1

Scott, W. B., and E. J. Crossman, 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184: 1–966.

Seesholtz, A. M., M. J. Manuel, and J. P. Van Eenennaam. 2015. First documented spawning and associated habitat conditions for Green Sturgeon in the Feather River, California. Environmental Biology of Fishes 98: 905–912.

Suttle, K. B., M. E. Power, J. M. Levine, and C. McNeely. 2004. How sediment in riverbeds impairs growth and survival of juvenile salmonids. Ecological Applications 14: 969–974.

USDI (U.S. Department of the Interior). 2008. Biological assessment on the continued long-term operations of the Central Valley Project and the State Water Project. USDI, Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.

Van Eenennaam, J. P., J. Linares-Casenave, X. Deng, and S. I. Doroshov. 2004. Effect of incubation temperature on green sturgeon embryos, (*Acipenser medirostris*). Environmental Biology of Fishes. 72: 145–154.

Appendices

Appendix A

Characteristics of Meso-habitat Units Measured during Boat-based Sonar Surveys

(*Due to sensitivity regarding holding locations of green sturgeon, appendix available upon request*)

Appendix B

Aerial Imagery of the Mainstem Eel River from Dos Rios to the Pacific Ocean, Including Surveyed Meso-habitat Units

(*Due to sensitivity regarding holding locations of green sturgeon, appendix available upon request)*