Chapter 8 Basic Biology and Life History of Green Sturgeon & Factors that May Influence Green Sturgeon Distribution and Abundance

In 2006 the Southern Distinct Population Segment (DPS) of North American green sturgeon (green sturgeon) were listed as threatened under provisions of ESA. The Southern DPS includes green sturgeon that spawning and living in the Sacramento River, Sacramento-San Joaquin Delta and the San Francisco Bay Estuary. The spawning migrations and spawning by green sturgeon in the upper Sacramento River mainstem have been well documented over the last 15 years. In addition, it has been surmised that spawning by green sturgeon may taken place at one time in the lower San Joaquin River. However, specific empirical estimates of abundance are not available for green sturgeon throughout the action area. There are several factors which affect green sturgeon populations including: fish passage, low flows, entrainment, loss of historical habitat, warm water temperatures, contaminants, and illegal harvest. As long-lived, late maturing fish that spawn periodically, green sturgeon are particularly susceptible to threats from overfishing. Green sturgeon are regularly caught in the sport, commercial, and tribal fisheries, particularly in Oregon and Washington commercial fisheries.

Although spawning and migration patterns for the green sturgeon have been well documented in recent years, designation of critical habitat and a recovery plan has not yet been developed for green sturgeon. A principle threat to green sturgeon is the reduction of spawning areas as the result of impassible barriers, primarily Keswick Dam on the Sacramento River and Orville Dam on the Feather River, that block access to historic spawning habitat for several anadromous species. Physical conditions in the Sacramento River and Delta vary substantially from year to year and these factors could drastically affect green sturgeon spawning success, dispersal patterns, and vulnerability to salvage.

There have also been substantial changes in water project operations in the decades since the CVP and SWP were built. These include a variety of actions implemented to protect listed salmonids as well as delta smelt. Concerted efforts have been made to reduce the effects of the projects on all fish. The seasonal timing of export pumping has been changed to weight summer pumping more heavily in order to reduce export pumping when listed salmon, steelhead and delta smelt are in the estuary. Delta Cross Channel (DCC) gate operations are also restricted in spring to protect juvenile salmon migrating downstream. CVP and SWP operations are managed to limit impacts on listed species during migration periods. Coincidently, many of the protective actions for the listed species also benefit the green sturgeon such as increased flows and temperature management and fish screen implementation. Finally, Reclamation is currently working closely with NMFS to develop specific project operation criteria for the Red Bluff Diversion Dam (RBDD) to protect green sturgeon.

Listing Status

On April 7, 2006, NOAA’s National Marine Fisheries Service (NMFS) issued a final rule listing the Southern distinct population segment (DPS) of North American green sturgeon (*Acipenser medirostris*) (green sturgeon) as a threatened species, which took effect on June 6, 2006 (71 FR

17757). Green sturgeon is a Class 1 (qualifying as threatened under the California ESA) Species of Special Concern in California (DFG 2003). Included in the listing is the green sturgeon population that spawns in the Sacramento River and live in the Sacramento River, the Sacramento-San Joaquin Delta, and the San Francisco Bay Estuary. This threatened determination was based on the reduction of potential spawning habitat, the severe threats to the single remaining spawning population, the inability to alleviate these threats with the conservation measures in place, and the decrease in observed numbers of juvenile Southern DPS green sturgeon collected in the past two decades compared to those collected historically (NMFS 2006).

Initially, available data did not indicate declining populations within the northern DPS, but due to uncertainty about the status and threats to these populations, NMFS placed the northern DPS on the Species of Concern List (70 FR 17386). After a status review was completed in 2002 (Adams et al. 2002), NMFS determined that the northern and southern DPSs of the North American green sturgeon did not warrant listing as threatened or endangered (68 FR 4433) but should be listed as a Species of Concern because of uncertainties about population structure and status (69 FR 19975). The “not warranted” determination was challenged on April 7, 2003. NMFS updated their status review on February 22, 2005, and determined that the southern DPS should be listed as threatened under the Federal Endangered Species Act (Biological Review Team 2005; 71 FR 17757).

Critical Habitat

Critical habitat has not been designated for the Southern DPS of green sturgeon.

Recovery Goals

A recovery plan has not been developed for green sturgeon and recovery planning efforts for this species are not yet underway. Green sturgeon were considered in the 1995 Sacramento-San Joaquin Delta Native Fishes Recovery Plan (USFWS 1996). This plan identifies a primary restoration (recovery) objective of a minimum population of 1,000 fish over 1 meter (39 inches) total length each year, including 500 females over 1.3 meters (51 inches) total length (minimum size at maturity), during the spawning period (presumably March-July) when spawners are present in the estuary and the Sacramento River.

Biology and Life History

Description

Sturgeon are among the largest and most ancient of bony fishes. They are placed, along with paddlefishes and numerous fossil groups, in the infraclass Chondrostei, which also contains the ancestors of all other bony fishes. The sturgeon themselves are not ancestral to modern bony fishes but are a highly specialized and successful offshoot of ancestral chondrosteans, retaining such ancestral features as a heterocercal tail, fin structure, jaw structure, spiral valve intestine, and spiracle. They have a cartilaginous skeleton and possess a few large ossified plates, called scutes, instead of scales. Sturgeon are highly adapted for preying on benthic organisms (e.g., clams, shrimp, etc.), which they detect with a row of extremely sensitive barbells on the underside of their snouts. They protrude their extraordinarily long and flexible “lips” to suck up food. Sturgeon are confined to temperate waters of the Northern Hemisphere. Of 25 extant species, only two live in California, the green sturgeon and the white sturgeon (*A. transmontanus*). (Moyle 2002)

Green sturgeon are similar in appearance to the sympatric white sturgeon, except the barbells are closer to the mouth than the tip of the long, narrow snout (Figure 8-1). The dorsal row of scutes numbers 8-11, lateral rows, 23-30, and bottom rows, 7-10; there is one large scute behind the dorsal fin as well as behind the anal fin (both lacking in white sturgeon). The scutes also tend to be sharper and more pointed than in white sturgeon. The dorsal fin has 33-36 rays, the anal fin, 22-28. The body color is olive green with an olivaceous stripe on each side; the scutes are paler than the body (Moyle 2002).

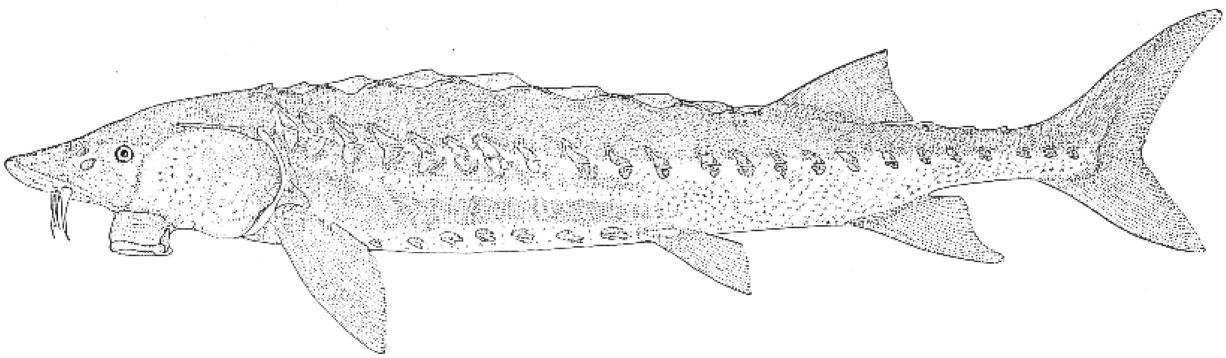

Figure 8-1. Image of Green Sturgeon.

As anadromous fish, sturgeon rely on riverine, estuarine, and marine habitats in the course of their long life. The ecology and life history of green sturgeon have received little study, evidently because of the generally low abundance, limited spawning distribution, and low commercial and sport fishing value of the species (Moyle 2002; Adams et al. 2002).

Green sturgeon is the most marine species of sturgeon, coming into rivers mainly to spawn (Moyle 2002). The majority of a green sturgeon's life is spent in the ocean following a one to three year freshwater rearing period (Nakamoto et al. 1995). Adult green sturgeon return to freshwater for spawning at around age 15 or older, with additional spawning migrations at two to four year intervals up to age 30-40 (Moyle 2002; Erickson and Webb 2007; VanEenennaam 2002; Cech et al. 2000). Green sturgeon life history could be divided into three phases: 1) freshwater juveniles (<3 years old); 2) coastal migrants; and 3) adults (FWS 1995).

Sturgeon live a long time (40-50 years), delay maturation to large sizes (125 cm total length), and spawn multiple times over their lifespan. This life history strategy has proven to be successful in the face of normal environmental variation in the large river habitats where spawning occurs. The sturgeon's long lifespan, repeat spawning in multiple years, and high fecundity allows them persist through periodic droughts and environmental catastrophes. The high fecundity that comes with large size allows them to produce large numbers of offspring when suitable spawning conditions occur and compensate for years of poor reproductive and juvenile rearing conditions. Adult green sturgeon do not spawn every year and only a fraction of the population enters freshwater where they might be at risk of a catastrophic event in any year (Beamesderfer et al. 2007).

Size, Age and Maturation

Size, age, and maturation data are limited for the southern DPS but may be similar to that of the northern DPS. For the Klamath River green sturgeon, an average length of 1.0 m is attained in 10 years, 1.5 m by age 15, and 2.0 m by 25 years of age (FWS 1993; Van Eenennaam 2006). The largest reported green sturgeon weighed about 159 kg and was 2.1 m in length (FWS 1993). The largest green sturgeon have been aged at 42 years, but this is probably an underestimate, and maximum ages of 60-70 years or more are likely (Moyle 2002). Newly hatched green sturgeon are typically between 8-19 mm in length and juveniles range between 2-150 cm (Emmett et al. 1991).

Adult green sturgeon are believed to spawn every three to five years and reach sexual maturity at an age of 15 to 17 years (Tracy 1990; Erickson and Webb 2007; Webb and Erickson 2007). Male and female green sturgeon differ in age-at-maturity and size-at-age. Adult males range between 139 and 199 cm in length, and can mature as young as 15 years, but tend to live shorter lives (30 years max) (VanEenennaam et al. 2006). Adult females are typically between 157 and 199 cm in length, mature as early as age 17 and can live up to 40 years (Cech et al. 2000). In the highly productive ocean environment, green sturgeon grow at a rate of approximately seven centimeters per year until they reach maturity (Moyle 2002). Average size-at-age can vary between sub-populations (Adams et al. 2002).

Migration and Spawning

In the southern DPS, adult green sturgeon begin their upstream spawning migrations into the San Francisco Bay in March and reach Knights Landing on the Sacramento River during April (Heublein et al. 2006). Based on the distribution of sturgeon eggs, larvae, and juveniles in the Sacramento River, DFG (2002) indicated that green sturgeon spawn in late spring and early summer above Hamilton City, possibly up to Keswick Dam (Brown 2007). Peak spawning is believed to occur between April and June.

Preferred spawning habitats are thought to be deep, cool pools with turbulent water and large cobble (DFG 2002; Moyle 2002; Adams et al. 2002). Preferred spawning substrate is likely large cobble, but it can range from clean sand to bedrock (Moyle 2002). Eggs are broadcast and externally fertilized in relatively fast water and probably in depths greater than 3 m (Moyle 2002). Female green sturgeon produce 59,000-242,000 eggs, about 4.34 millimeters (mm) in diameter (Van Eenennaam et al. 2001, 2006). Though the number of eggs produced is relatively low compared to other sturgeon species, green sturgeon egg size is large (4.3 mm in diameter; Cech et al. 2000).

Green sturgeon were most often found at depths greater than 5m (16.4 feet) with low or no currents during summer and autumn months (Erickson et al. 2002). Recent acoustic tagging studies on the Rogue River (Erickson et al. 2002) found that adult green sturgeon held for as much as six months in deep (>5 m [16.4 feet]), low gradient reaches or off-channel sloughs or coves of the river during summer months when water temperatures were between 59-73˚F. When ambient temperatures in the river decrease in autumn and early winter (<50˚F), and flows increase, fish moved downstream into the ocean.

Egg Incubation and Rearing

Eggs are deposited at sites where they adhere to and between large rock substrate. The large size of green sturgeon eggs relative to other sturgeon indicates that female green sturgeon invest a greater amount of their reproductive energy resources into maternal yolk for nourishment of the embryo, which results in larger larvae (Van Eenennaam et al. 2001). The reserve of maternal yolk and larger larvae could provide an advantage in larval feeding and survival (Van Eenennaam et al. 2001). Compared with other acipenserids, green sturgeon larvae appear more robust and easier to rear (Van Eenennaam et al. 2001).

Both spawning areas and migratory corridors comprise rearing habitat for juvenile green sturgeon. Young green sturgeon appear to rear for the first one to two months in the Sacramento River between Keswick Dam and Hamilton City (DFG 2002). Rearing habitat condition and function may be affected by variation in annual and seasonal flow and temperature characteristics (70 FR 17386). Van Eenennaam et al. (2005) concluded from laboratory studies that temperatures 63–64°F may be the upper limit of the thermal optima for green sturgeon embryos. Temperatures of 73–79°F affected cleavage and gastrulation of green sturgeon embryos and all died before hatching (Van Eenennaam et al. 2005). Growth studies on younger juvenile green sturgeon determined that cyclical 66-75°F water temperature was optimal (Allen et al. 2006).

Hatchling green sturgeon embryos seek nearby cover, and remain under rocks (Deng et al. 2002). After about 6 to 9 days fish develop into larvae and initiate exogenous foraging up- and downstream on the bottom (Deng et al. 2002; Kynard et al. 2005). After a day or so, larvae initiate a downstream dispersion migration that lasts about 12 days (peak, 5 days). All young movement and foraging during the migration period is nocturnal (Cech et al. 2000; Kynard et al. 2005). Length at 10 days is 19 to 29 mm (mean 24 mm) (Deng et al. 2002). At an age of 15 to 21 days, green sturgeon are 30 mm or greater in length (Deng et al. 2002). Larval green sturgeon are regularly captured during this dispersal stage at about two weeks of age (24-34 mm fork length) in rotary screw traps at Red Bluff Diversion Dam (DFG 2002; FWS 2002), and three weeks old when captured further downstream at the Glen-Colusa facility (DFG, unpublished data; Van Eenennaam et al. 2001).

At the age of 45 days, metamorphosis is complete and green sturgeons are 70 to 80 mm in length (Deng et al. 2002). Post-migrant larvae are benthic, foraging up- and downstream diurnally with a nocturnal activity peak. Foraging larvae select open habitat, not structure habitat, but continue to use cover during the day. A second downstream migration occurs in the fall. Juveniles migrate downstream mostly at night to wintering sites, ceasing migration at temperatures of 45–46°F. During winter, juveniles select low light habitat, likely deep pools with some rock structure. 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). Juveniles grow rapidly, reaching 300 mm in 1 year and over 600 mm within 2-3 years (Nakamoto et al. 1995, FWS 1995). Juveniles spend from 1-4 years in fresh and estuarine waters of the Sacramento-San Joaquin Delta and disperse into salt water at lengths of 300-750 mm (FWS 1995).

Stomach contents from adult and juvenile green sturgeon captured in the Sacramento-San Joaquin Delta point to the importance of habitat that supports shrimp, mollusks, amphipods, and small fish (Radtke 1966; Houston 1988; Moyle et al. 1992). Stomachs of green sturgeon caught in Suisun Bay contained *Corophium* sp. (amphipod), *Cragon franciscorum* (bay shrimp), *Neomysis awatchensis* (Opossum shrimp: synonymous with *Neomysis mercedis*) and annelid worms (Ganssle 1966). Stomachs of green sturgeon caught in San Pablo Bay contained *C. franciscorum*, *Macoma* sp. (clam), *Photis californica* (amphipod), *Corophium* sp., *Synidotea laticauda* (isopod), and unidentified crab and fish (Ganssle 1966). Stomachs of green sturgeons caught in Delta contained *Corophium* sp. and *N. awatchensis* (Radtke 1966). As a result of recent changes in the species composition of macroinvertebrates inhabiting the Bay-Delta estuary, (due to non-native species introductions), the current diet of green sturgeon is likely to differ from that reported in the 1960's.

Ocean Residence

Based on their life history, a large percentage of the adult green sturgeon population inhabit the ocean at any given time (Beamesderfer et al. 2007). Green sturgeon typically stay near shore and avoid depths exceeding 100 m (Erickson and Hightower 2007). Relatively large concentrations of sturgeon occur in the Columbia River estuary, Willapa Bay, and Grays Harbor, with smaller aggregations in the San Francisco estuary and other coastal estuaries (Emmett et al. 1991; Moyle et al. 1992; ODFW 2005a; Israel 2006; Moser and Lindley 2007; Lindley et al. 2008). Adults feed in estuaries during the summer (ODFW 2005a; Moser and Lindley 2007). Annual marine survival rate was estimated at 0.83 for 2004 (Lindley et al. 2008), similar to the survival rate of 0.85 estimated for Klamath River green sturgeon by Beamesderfer and Webb (2002). Little is known about green sturgeon feeding at sea (DFG 2005a).

Population Distribution

North American green sturgeon are composed of two DPSs (Figure 8-2): the northern DPS includes all populations in the Eel River and northward, and the southern DPS includes a single spawning population in the Sacramento River (Adams et al. 2002). The northern DPS includes populations spawning in the Rogue, Klamath, and Umpqua rivers (NMFS 2005). Green sturgeon from the Sacramento River are genetically distinct from their northern counterparts indicating a spawning fidelity to their natal rivers (Israel et al. 2004).

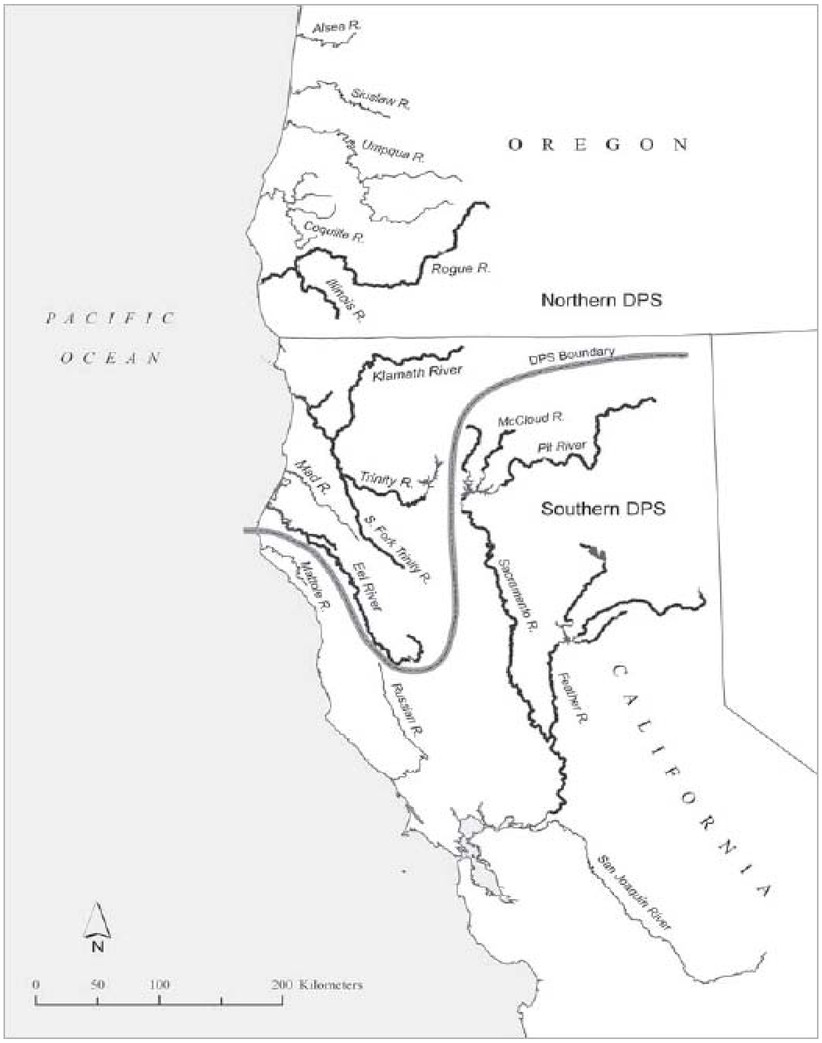

Figure 8-2. Distribution of North American Green Sturgeon of both the Northern and Southern Distinct Population Segments (NMFS 2007).

Sacramento River

Current data and observations document green sturgeon in the Sacramento River as far upstream as Keswick Dam and as far south as the CVP/SWP water export facilities near the southern limit of the Sacramento-San Joaquin Delta.

Spawning in the upper Sacramento River is currently thought to occur from Hamilton City (RM 200) to above Red Bluff Diversion Dam (RM 304). Spawning migrations and spawning by green sturgeon in the upper Sacramento River mainstem have been well documented over the last 15 years (Beamesderfer et al. 2004). Anglers fishing for white sturgeon or salmon commonly report catches of green sturgeon from the Sacramento River at least as far upstream as Hamilton City (Beamesderfer et al. 2004). Eggs, larvae, and post larval green sturgeon are now commonly reported in sampling directed at green sturgeon and other species (Beamesderfer et al. 2004; Brown 2007). Young-of-the-year (yoy) green sturgeon have been observed annually since the late 1980s in fish sampling efforts at Red Bluff Diversion Dam (RBDD) and the Glenn-Colusa

Canal (Beamesderfer et al. 2004). Green sturgeon have not been documented in Sacramento River tributaries other than the Feather River system (Beamesderfer et al. 2004, Moyle 2002).

The upstream extent of historical spawning by green sturgeon in the Sacramento River system is unknown. White sturgeon historically ranged into upper portions of the Sacramento system including the Pit River and a substantial number were trapped in and above Lake Shasta when Shasta Dam was closed in 1944 and successfully reproduced until the early 1960s (Beamesderfer *et al*. 2004). Green sturgeon have not been documented upstream from the Shasta Dam site. According to NMFS (2005), "the BRT considered it possible that the additional habitat behind Shasta Dam in the Pit, McCloud, and Little Sacramento systems would have supported separate populations or at least a single, larger Sacramento River population less vulnerable to catastrophes than one confined to a single mainstem, but the BRT was unable to be specific due to the paucity of historical information" (NMFS 2005).

Green sturgeon currently spawn in the Sacramento mainstem downstream from Keswick and Shasta dams. NMFS concluded that it is unlikely that green sturgeon reproduced in their current spawning area under the historical temperature regime that occurred before the construction of Shasta and Keswick dams (NMFS 2005). NMFS (2005) further concluded: "we have not been able to quantify the reduction of habitat to date, and are uncertain how reduction in spawning habitat has affected the population's viability." However, Shasta Dam operations now maintain relatively favorable temperature conditions in the upper Sacramento River while pre-development patterns were characterized by very high annual variation with periods of extended drought. The net tradeoff in habitat lost vs. habitat gained is unclear.

Prehistoric distribution of sturgeon in California has been mapped by Gobalet et al. 2004 based on bones at Native American archaeological sites. Data were reported on dozens of sites throughout California and summarized by county. Sturgeon remains were observed in 12 counties, all in the Central Valley. Observations were concentrated at San Francisco Bay and Sacramento-San Joaquin and delta sites (Contra Costa, Alameda, San Francisco, Marin, Napa, San Mateo and Santa Cruz counties). Historical 18th-century accounts report the aboriginal gillnetting and use of tule balsa watercraft for the capture of sturgeon, and fishing weirs were also likely employed on bay tidal flats (Gobalet et al. 2004). Most sturgeon were unidentified species but green sturgeon were specifically identified from Contra Costa and Marin county sites. Sturgeon remains (unidentified species) were also identified from lower Sacramento River counties (Sacramento, Yolo, Colusa, Glenn, and Butte counties). No sturgeon remains were found in samples from the upper Sacramento River although other fish species including salmonids were reported in those areas.

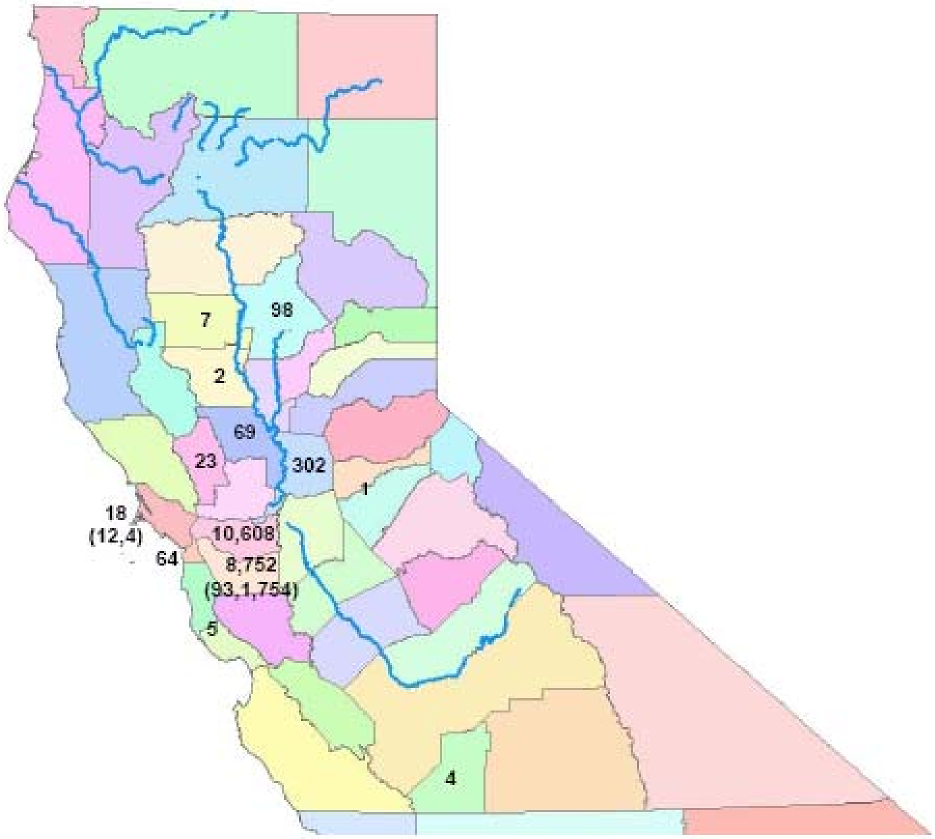

Figure 8-3. Observations of sturgeon remains in the California Native American archaeological sites. (Gobalet et al. 2004). Numbers represent number of sturgeon observations based on skeletal remains. Numbers are typically unidentified sturgeon species. Species-specific identifications are listed in parentheses (green sturgeon, white sturgeon).

Feather River

Historical and recent information confirms that both green and white sturgeons occasionally range into the Feather, Yuba, and Bear rivers but numbers are low (Beamesderfer et al. 2004). Most recently in 2006, a dozen sturgeon were observed to either be captured by anglers or rolling at the surface near the Thermalito Outlet located on the Feather River. Of these, four were able to be positively identified as green sturgeon by DWR biologists (DWR unpublished data, DWR 2007).

It is unknown whether green sturgeon historically spawned in the Feather River either downstream or upstream of Oroville Dam or the Thermolito Afterbay outlet. Unspecific historical reports of green sturgeon spawning in the Feather River (Wang 1986, USFWS 1995, DFG 2002, DWR 2007) have not been corroborated by observations of young fish or significant numbers of adults in focused sampling efforts (Schaffter & Kohlhorst 2002, Niggemyer & Duster 2003, Seesholtz 2003, Beamesderfer et al. 2004). Potential confusion of green and white sturgeon often confounds interpretation of historical records. White sturgeon have been documented in the Feather River system on numerous occasions (Anonymous 1918, Talbitzer 1959, Miller 1972, USFWS 1995, Schaffter and Kohlhorst 2002, Beamesderfer et al. 2004).

Significant habitat on the Lower Feather River, while modified, remains accessible downstream from the Thermolito Afterbay outlet (DWR 2005a). Potential natural and man-made barriers to upstream movements in the Feather River during low flow years might also limit significant movement of Southern DPS green or white sturgeon into the Feather River to wet, high flow water years (Beamesderfer et al. 2004).

San Joaquin River

The current or historical occurrence of green sturgeon in the San Joaquin River has been a source of much speculation. It is unclear whether green sturgeon were historically present, are currently present, or were historically present and have been extirpated from the San Joaquin River (NMFS 2005, Beamesderfer et al. 2007). No adult or juvenile green sturgeon have been documented in the San Joaquin River upstream from the Delta (DFG 2002), although no directed sturgeon studies have ever been undertaken in the San Joaquin River (FWS 1995, DFG 2002, Adams et al. 2002, Beamesderfer et al. 2004, NMFS 2005). Observations of green sturgeon juveniles or unidentified sturgeon larvae in the San Joaquin River has been limited to the Delta where they could easily, and most likely, have originated from the Sacramento River rather than the San Joaquin River (Beamesderfer et al. 2004).

Moyle et al. (1992) surmised that spawning by green sturgeon may have taken place at one time in the lower San Joaquin River. Others have noted the long history of habitat changes in the San Joaquin River basin and assumed historical use by green sturgeon based on the past habitat suitability for spring-run Chinook salmon and steelhead. Sturgeon remains (unidentified species) in deposits at Tulare Lake illustrate that anadromous species were historically capable of reaching the south San Joaquin Valley (Gobalet et al. 2004) but no green or white sturgeon appear to have been trapped behind Friant Dam when it was constructed in the 1940s (DFG 2002). White sturgeon are regularly observed in the San Joaquin River upstream from the Delta (Beamesderfer et al. 2004) and spawning is suspected to occur in wet years (Shaffter, DFG retired, 2004 personal communication). Small fisheries for sturgeon occur in late winter and spring between Mossdale and the Merced River (Kohlhorst 1976, Kohlhorst et al. 1991, Scott 1993, Lewis 1995, Palomares 1995, Keo 1996, Jardine 1998).

Bay-Delta

Green sturgeon juveniles, subadults, and adults are widely distributed in the Sacramento-San Joaquin Delta and estuary areas including San Pablo Bay (Beamesderfer et al. 2004). The Sacramento-San Joaquin Delta serves as a migratory corridor, feeding area, and juvenile rearing area for North American green sturgeon in the southern DPS. Table 8-1 depicts the season occurence of green sturgeon life stages in freshwater habitat throughout the California Central Valley and its neighboring marine environments.

Adults migrate upstream primarily through the western edge of the Delta into the lower Sacramento River between March and June (Adams et al. 2002). Larvae and post-larvae are present in the lower Sacramento River and North Delta between May and October, primarily in June and July (DFG 2002). Juvenile green sturgeon have been captured in the Delta during all months of the year (Borthwick et al. 1999; DFG 2002; BDAT 2007). Catches of 1 and 2 year old Southern DPS green sturgeon on the shoals in the lower San Joaquin River, at the CVP/SWP fish salvage facilities, and in Suisun and San Pablo bays indicate that some fish rear in the estuary for at least 2 years (DFG 2002). Larger juvenile and subadult green sturgeon occur throughout the estuary, possibly temporarily, after spending time in the ocean (DFG 2002; Kelly et al. 2007). Figure 8-4 shows the size distribution of green sturgeon at various life stages observed in sample data from young-of-the-year collected in spring and summer at RBDD in the Sacramento River, juveniles salvaged from CVP/SWP water projects, and subadults sampled by DFG in San Pablo Bay.

Table 8-1. The temporal occurrence of (a) adult, (b) larval and post-larval, (c) juvenile, and (d) coastal migrants of the southern DPS of North American green sturgeon. Locations are specific to the Central Valley of California. Darker shades indicate months of greatest relative abundance.

(a) Adult (≥13 years old for females and ≥9 years old for males)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
[1,2,3]Upper Sac. River			Medium	Medium / High	High	High / Medium	Medium	Medium	Medium	Medium	Medium	
[4,8]SF Bay Estuary			Medium	Medium	Medium	Medium	Medium	Medium	Medium			

(b) Larval and post-larval (≤10 months old)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
[5]RBDD, Sac River					Medium	High	High	Medium				
[5]GCID, Sac River					Medium	High	High	Medium	Low	Low		

(c) Juvenile (> 10 months old and ≤3 years old)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
[6]South Delta*	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
[6]Sac-SJ Delta	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
[5]Sac-SJ Delta				Medium	Medium	Medium	Medium	Medium	Medium	Medium		
[5]Suisun Bay	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium

(d) Coastal migrant (3-13 years old for females and 3-9 years old for males)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
[3,7]Pacific Coast	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Source: [1]FWS 2002; [2]Moyle et al. 1992; [3]Adams et al. 2002 and NMFS 2005; [4]Kelley et al. 2006; [5]DFG 2002; [6]Interagency Ecological Program Relational Database, fall midwater trawl green sturgeon captures from 1969 to 2003; [7]Nakamoto et al. 1995; [8]Heublein et al. 2006, * Fish Facility salvage operations

RBDD – Red Bluff Diversion Dam GCID – Glen-Colusa Irrigation District facility

Relative Abundance: =High = Medium = Low

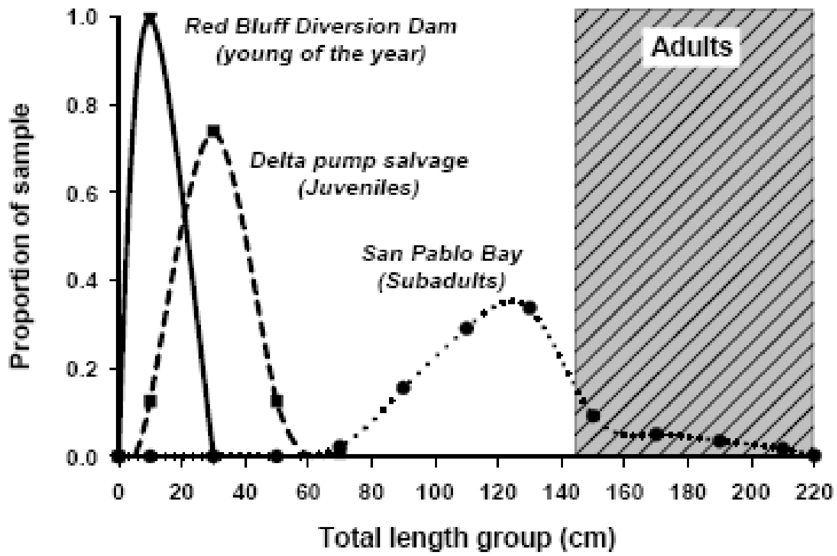

Figure 8-4. Sizes of juvenile green sturgeon measured at CVP/SWP fish salvage facilities, 1968-2001 (DFG 2002), collected in rotary 1994-2000 (FWS 2002), and sampled in semi-annual San Pablo Bay sturgeon stock assessments (DFG 2002). [Figure from Beamesderfer et al. 2007]

Ocean

Green sturgeon from the Southern DPS pass through the San Francisco Bay to the ocean where they commingle with other sturgeon populations (DFG 2002). Green sturgeon are known to range in nearshore marine waters from Mexico to the Bering Sea, with a general tendency to head North after their out-migration from freshwater (NMFS 2005). They are commonly observed in bays and estuaries along the western coast of North America during the late summer (Emmett et al. 1991; Moyle et al. 1992; ODFW 2005a; Israel 2006; Moser and Lindley 2007; Lindley et al. 2008). Both the Northern DPS green sturgeon and Southern DPS green sturgeon occur in large numbers in the Columbia River estuary, Willapa Bay, and Grays Harbor, Washington (NMFS 2005).

Subadult and adult sturgeon tagged in San Pablo Bay oversummer in bays and estuaries along the coast of California, Oregon, and Washington, between Monterey Bay and Willapa Bay, before moving further north in the fall to overwinter north of Vancouver Island. Individual Southern DPS green sturgeon tagged by the DFG in the San Francisco Estuary have been recaptured off Santa Cruz, California; in Winchester Bay on the southern Oregon coast; at the mouth of the Columbia River; and in Gray’s Harbor, Washington (FWS 1993; Moyle 2002). Most tags for Southern DPS green sturgeon tagged in the San Francisco Estuary have been returned from outside that estuary (Moyle 2002).

Lindley et al. (2008) investigated marine migrations of green sturgeon by tagging subadults and adults from northern and southern DPSs with ultrasonic pinger tags. An array of receivers off the coast of California, Oregon, Washington, British Columbia and Alaska tracked their northern and southern migrations. Most tagged sturgeon moved north along the coast in the fall to spend winters north of Vancouver Island and south of southeast Alaska, and returned in the spring to oversummer in California, Oregon and Washington bays and estuaries. Distribution patterns of fish from different tagging locations varied. Green sturgeon from all spawning populations appear to migrate north as far as Brooks Peninsula but vary in the extent of their southerly spring migrations (Lindley et al. 2008). Marine migrations of green sturgeon may include areas as far south as Monterey Bay and as far north as Brooks Peninsula, Vancouver, BC.

Abundance and Trends in the Action Area

Empirical estimates of green sturgeon abundance are not available for any west coast population including the Sacramento River population. Interpretations of available time series of abundance index data for green sturgeon are confounded by small sample sizes, intermittent reporting, fishery-dependent data, lack of directed sampling, subsamples representing only a portion of the population, and potential confusion with white sturgeon (Heppell and Hofmann 2002, Adams et al. 2002). This section summarizes the best available data and identifies qualifications to be considered in its application as a description of the current baseline.

Population Estimates

The most consistent sample data for Sacramento green sturgeon is for subadults captured in San Pablo Bay during periodic white sturgeon assessments since 1948. DFG measured and identified 15,901 sturgeon of both species between 1954 and 1991 (FWS 1996). Catches of subadult and adult North American green sturgeon by the Interagency Ecological Program (IEP) between 1996 and 2004 ranged from one to 212 green sturgeon per year, with the highest catch in 2001 (Samantha Vu, DFG, pers. comm. 2005). Various attempts have been made to infer green sturgeon abundance based on white sturgeon mark-recapture estimates and relative numbers of white and green sturgeon in the catch (FWS 1996, Moyle 2002). However, low catches of green sturgeon preclude estimates or indices of green sturgeon abundance from this data (Schaffter and Kohlhorst 1999, Gingras 2005). It is unclear if the high annual variability in length distributions in these samples (Figure 8-5) reflect variable recruitment and abundance or are an artifact of small sample sizes, pooling of sample years, or variable distribution patterns between freshwater and ocean portions of the population.

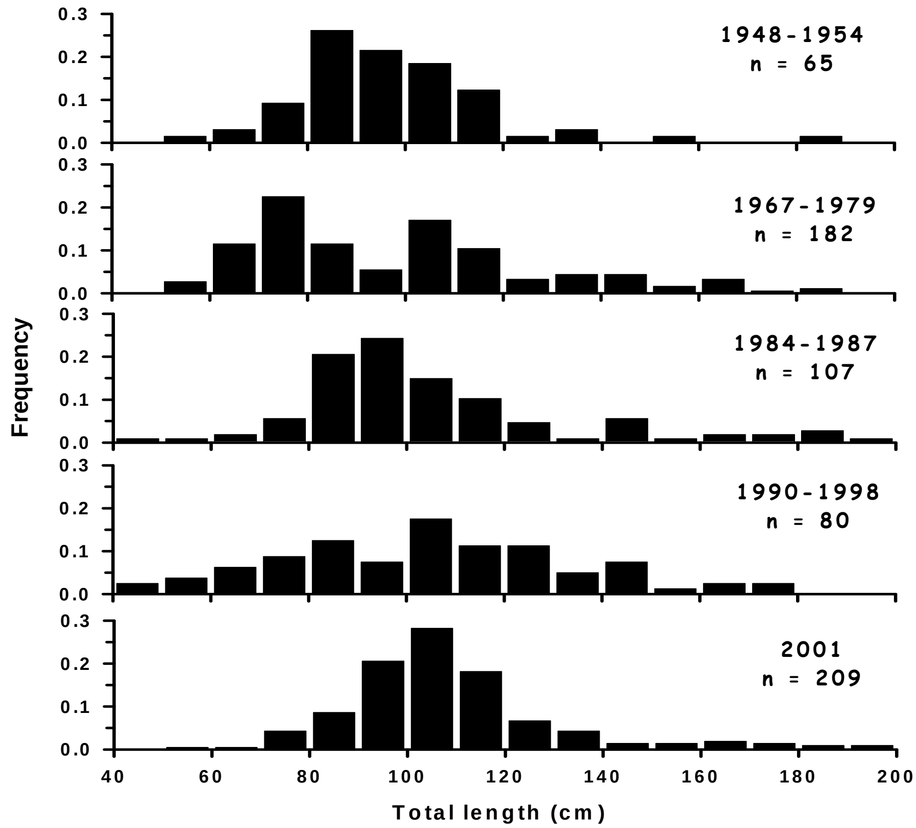

Figure 8-5. Changes in length distribution over time based on trammel net sampling of subadult green sturgeon in San Pablo Bay (DFG 2002). [Figure from Beamesderfer et al. 2007]

Migrant Sampling

Anecdotal information is also available on young-of-the-year green sturgeon from juvenile fish monitoring efforts at RBDD and the Glenn-Colusa Irrigation District pumping facility on the upper Sacramento River. Fish traps have been operated below RBDD and at the Glenn-Colusa Irrigation District (GCID) pumping plant. These facilities report sampling of between zero and 2,068 juvenile green sturgeon per year (Adams et al. 2002) and suggest that at least some green sturgeon reproduction occurred during the 1990s (Beamesderfer 2005).

Approximately 3,000 juvenile green sturgeon have been observed in rotary screw traps operated for juvenile salmon at RBDD from 1994-2000 (Figure 8-6). Annual catches have declined over the period from 1995 through 2000 although the relationship of these catches to actual abundance is unknown. Over 2,000 juvenile green sturgeon have been collected in fyke and rotary screw traps operated at the GCID Diversion from 1986-2003 (Figure 8-7). Operation of the screw trap at the GCID site began in 1991 and has continued year-around with the exception of 1998. Juvenile green sturgeon at the GCID site were consistently larger in average size, but the number captured varied widely (0 to 2,068 per year) with no apparent patterns in abundance between the two sites. Abundance of juveniles peaked during June and July with a slightly earlier peak at the RBDD site (Adams et al. 2002).

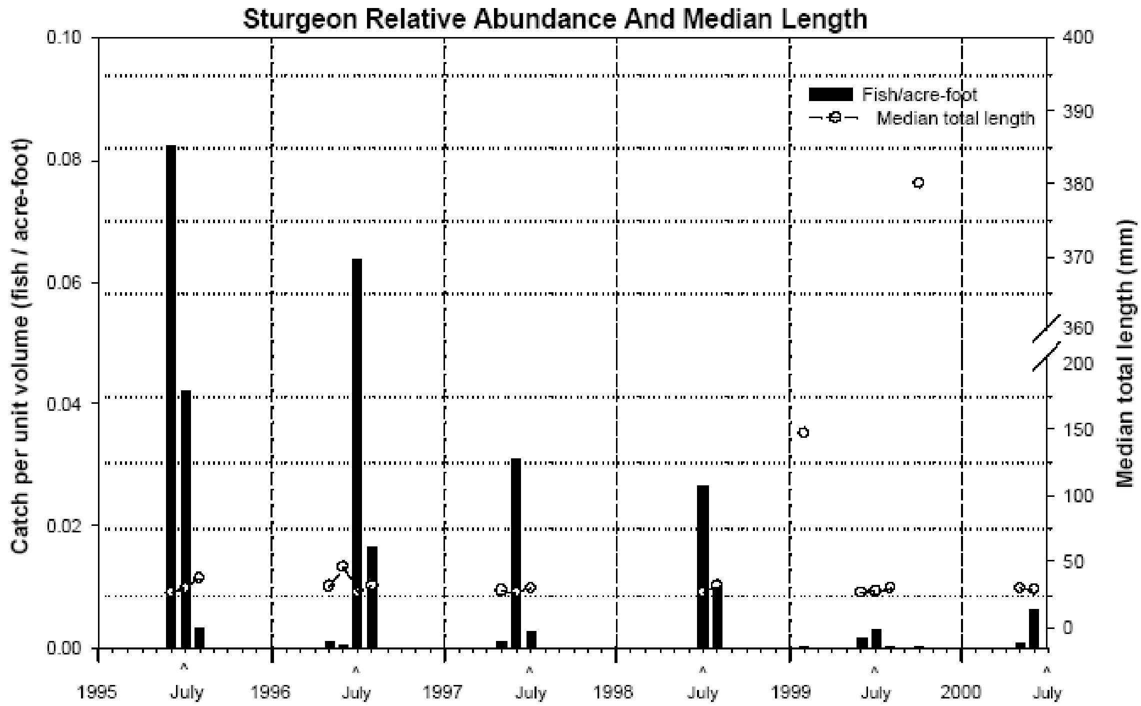

Figure A3. Relative abundance (fish/acre-foot) and median length for juvenile sturgeon (*Acipenser spp.*) captured by rotary-screw traps at Red Bluff Diversion Dam (RK 391), Sacramento River, CA. Data summarized from January 1995 through June 2000. In 1996 and 1997, a total of 124 juvenile sturgeon (*Acipenser spp.*) were grown out and positively identified as green sturgeon (*Acipenser medirostris*).

Figure 8-6. Green sturgeon data sample data from Red Bluff Diversion Dam rotary screw trap monitoring (FWS 2002).

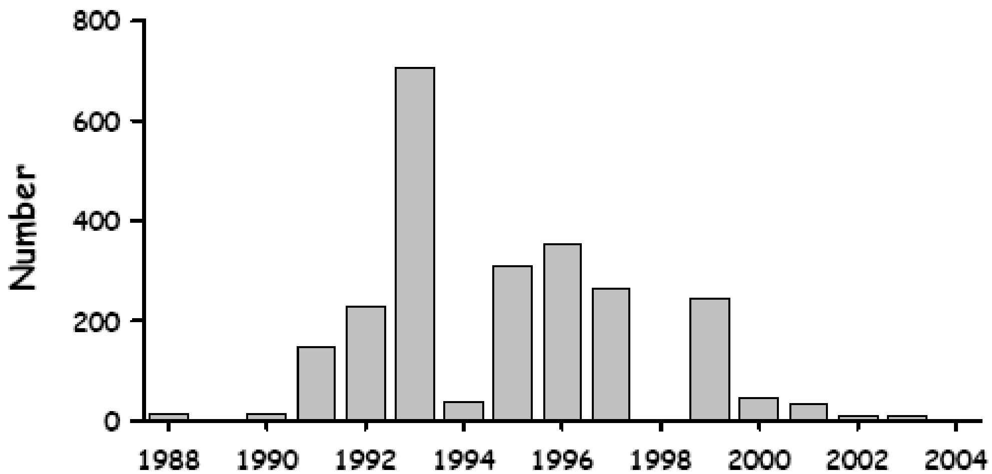

Figure 8-7. Juvenile green sturgeon collected in fyke and rotary screw traps operated at the Glenn-Colusa Irrigation District Diversion from 1986-2003 (Beamesderfer 2005).

Salvage Numbers

Variable numbers of juvenile green sturgeon are observed each year from two south Delta water diversion facilities (DFG 2002). When water is exported through the CVP/SWP export facilities, fish become entrained into the diversion. Since 1957, Reclamation has salvaged fish at the Tracy Fish Collection Facility. DFG's Fish Facilities Unit, in cooperation with DWR, began salvaging fish at the Skinner Delta Fish Protective Facility in 1968. The salvaged fish are trucked daily and released at several sites in the western Delta. Salvage of fish at both facilities is conducted 24 hours a day, seven days a week at regular intervals. Entrained fish are subsampled for species composition and numbers.

Numbers of green sturgeon observed at these fish facilities have declined since the 1980s (Figure 8-8) which contributed to NMFS' decision to list the southern DPS as a threatened species. In the Delta, the average number of green sturgeon salvaged per year at the SWP Skinner Fish Facility was 87 individuals between 1981 and 2000, and 20 individuals from 2001 through 2007 (71 FR 17759). From the CVP Tracy Fish Collection Facility, green sturgeon counts averaged 246 individuals per year between 1981 and 2000, and 53 individuals from 2001 through 2007 (M. Donnellan, unpubl. data). Patterns were similar between total numbers per year and numbers adjusted for water export volumes which increased during the 1970s and 1980s (Figure 8-9).

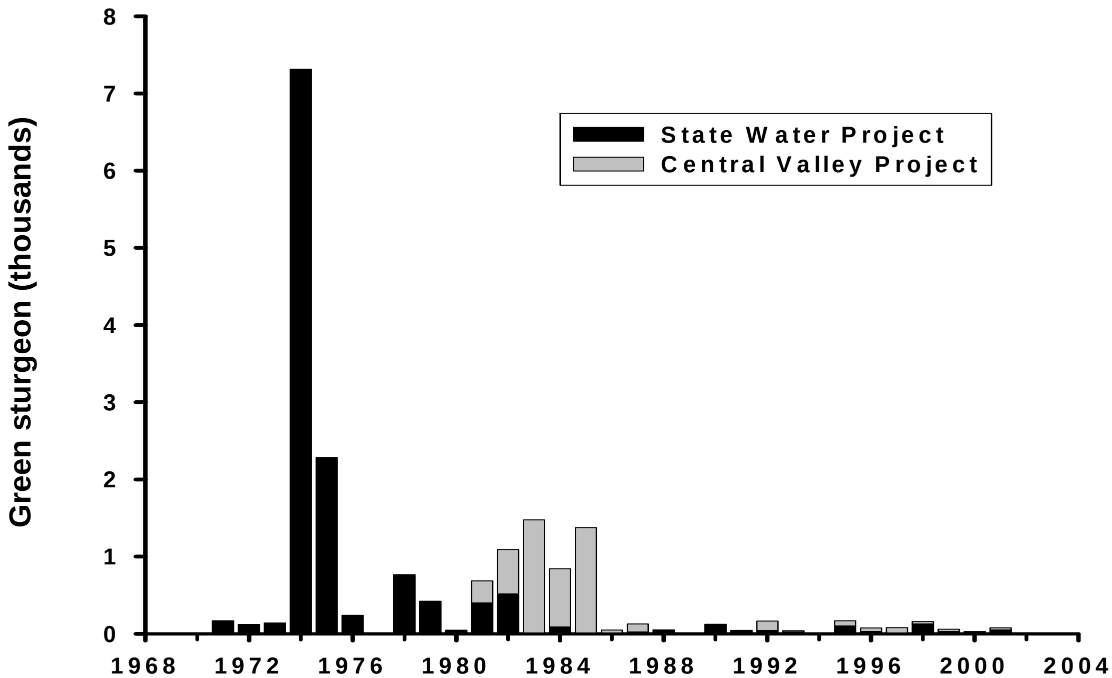

Figure 8-8. Estimated annual salvage of green sturgeon at SWP and CVP fish facilities in the South Sacramento-San Joaquin River delta. Green sturgeon were not counted at the Federal Central Valley Project prior to 1981. (Data from DFG 2004). Figure from Beamesderfer et al. (2007).

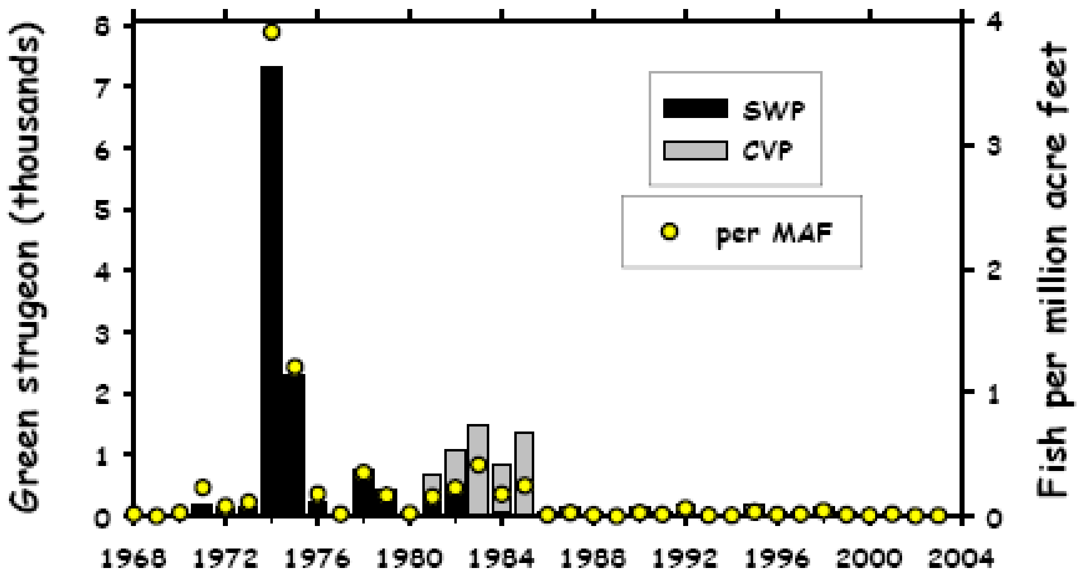

Figure 8-9. Estimated annual salvage of green sturgeon at CVP and SWP fish facilities in the South Sacramento-San Joaquin River Delta (DFG 2002). Prior to 1981, green and white sturgeon were counted together and reported simply as sturgeon at the CVP.

Salvage catches of green sturgeon at the SWP and CVP facilities appears to be primarily juvenile fish approximately 1 to 3 years of age (Figure 8-10). Salvage catches come from the population of juvenile green sturgeon that rear year-round throughout the Delta for several years before dispersing into the ocean. This group of fish may reflect multiple year classes. Green sturgeon are observed in the salvage in all months of the year but are most common in summer and early fall with a peak in August (Figure 8-11).

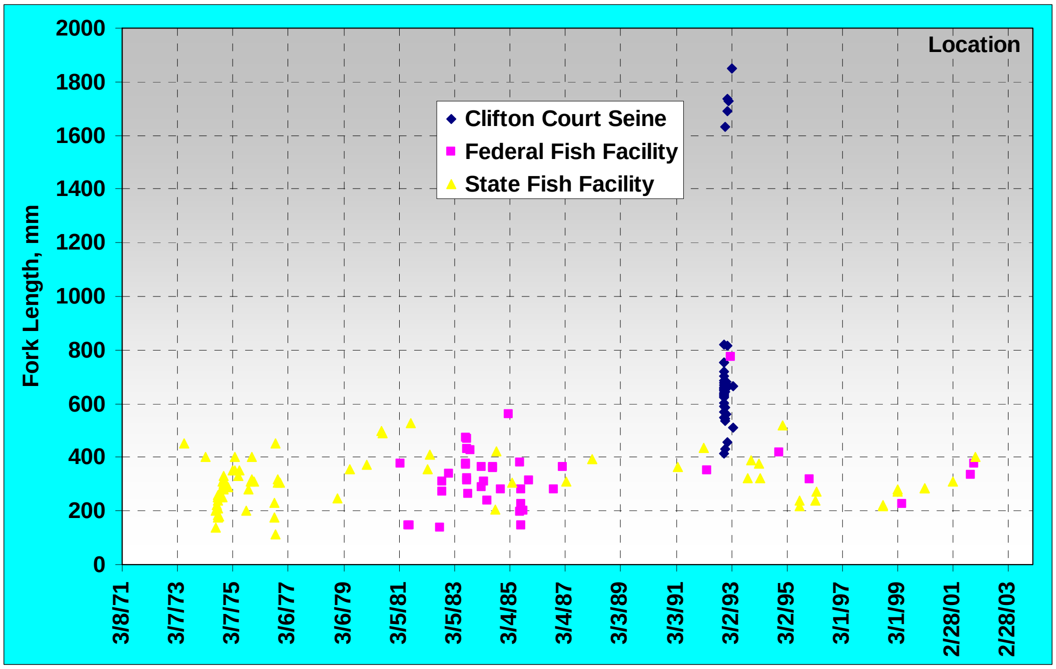

Figure 8-10. Fork lengths of green sturgeon collected at the CVP and SWP fish facilities and by seine in Clifton Court Forebay (data from DFG 2002).

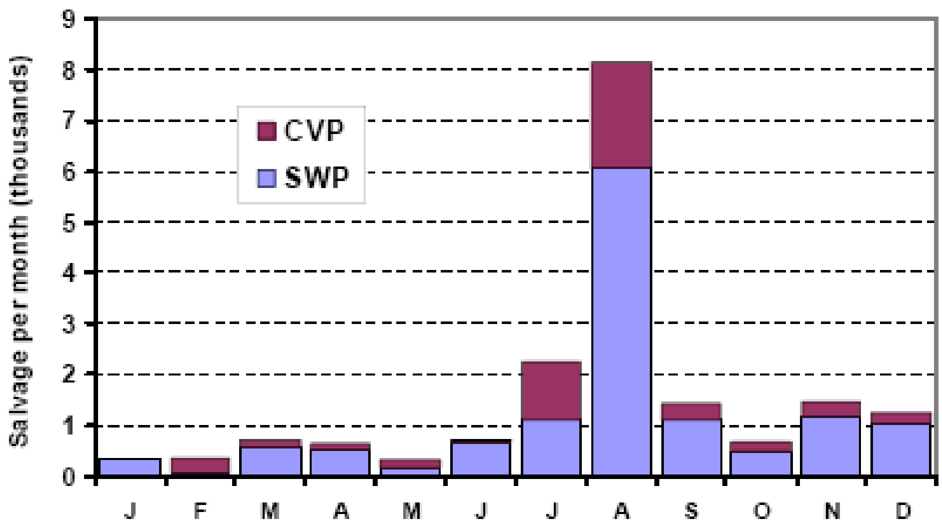

Figure 8-11. Seasonal pattern of juvenile green sturgeon catches at State and Federal fish facilities, 1968-2001 (DFG 2002).

Annual counts of green sturgeon from the SWP and CVP fish facilities are not significantly correlated (Figure 8-12) (Beamesderfer 2005). Data on green sturgeon are available for both facilities from 1981-2005. Only 1 percent of the variability in salvage numbers was correlated between facilities (typically $p<0.10$ or $p<0.05$) (Beamesderfer 2005). In 1983, projected salvage at the CVP was 1,475 and only 1 at the SWP. In 1985, projected salvage at the CVP was 1,374 and only 3 at the SWP (Beamesderfer 2005).

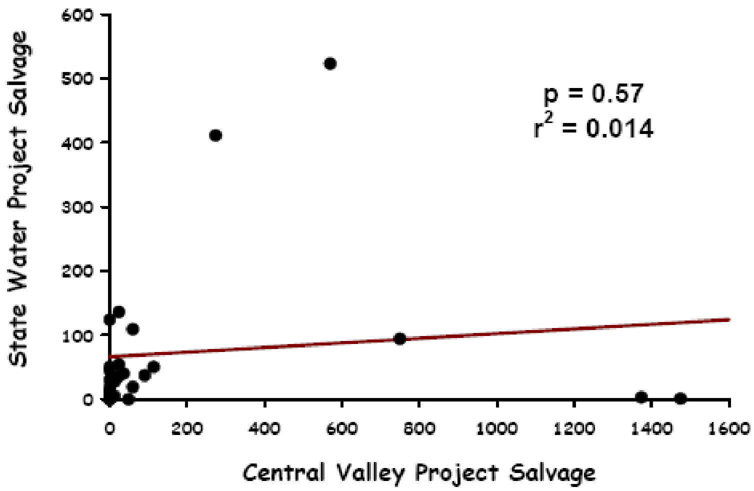

Figure 8-12. Green sturgeon salvage numbers at State and Federal facilities are not statistically correlated (Beamesderfer 2005).

Physical conditions in the Sacramento River and Delta vary substantially from year-to-year and these factors could drastically affect green sturgeon spawning success, dispersal patterns, and vulnerability to salvage. There have also been substantial changes in CVP and SWP water project operations in the decades since the CVP and SWP were built. Changes in SWP and CVP operations, particularly in recent years, include a variety of actions implemented to protect listed salmon (NMFS 2004) as well as delta smelt. Concerted efforts have been made to reduce the effects of projects on fish. The seasonal timing of export pumping has been changed to weight summer pumping more heavily in order to reduce export pumping when listed salmon, steelhead and delta smelt are in the estuary during the late-winter and spring. Delta Cross Channel (DCC) gate operations are also restricted in late-winter and spring to protect juvenile salmon migrating downstream. CVP and SWP water project operations are managed to limit impacts on listed species during migration periods.

Peak catches of both green and white sturgeon prior to 1985 were generally correlated with high Sacramento River flows (Figure 8-13). NMFS (2005) noted the relationships between flow and apparent white sturgeon spawning success and inferred that low flow rates might affect green sturgeon in a similar manner. Declines in green sturgeon salvage numbers since the 1980s corresponded with an eight-year period of low flows (Figure 8-13) when conditions might have been less favorable for sturgeon reproduction. Periodic high flows in the 1990s produced small increases in white sturgeon salvage catches but salvage numbers were much lower than prior to 1985 (Figure 8-13). FWS (1996) in the FWS Recovery Plan for Sacramento/San Joaquin Delta

Native Fishes also reported that juvenile sturgeon are probably more vulnerable to entrainment at the SWP and CVP at low to intermediate flows during those years when river and Delta inflow are normal or below normal.

FWS (1996) reported substantial uncertainty in the interpretation of salvage data for green sturgeon because of poor quality control on both counts and species identification, expansions from small sample sizes, variability in sturgeon dispersal patterns and collection vulnerability in response to complex changes in delta flow dynamics, and changes in configuration and operation over time. Estimated sturgeon salvage numbers are expanded from subsamples and actual numbers of green sturgeon observed are substantially smaller. Historical expansions were based on variable expansion rates (subsample duration) ranging from 15 seconds per two hours when fish numbers were high to 100 percent counting during periods when fish numbers were low. Now, NMFS 2004 required sampling of fish salvage at both the SWP and CVP facilities at intervals of no less than 10 minutes every 2 hours. Green sturgeon salvage estimates reported for years before 1993 may be in error because of uncertainty whether smaller sturgeon were correctly identified (FWS 1996; DFG 2002; DFG 2005b; FWS 2005). Reclamation and DWR recommended that only more recent (from 1993 and later) CVP and SWP salvage data should be used to analyze the effects of water project operations on the green sturgeon and other anadromous fishes (FWS 2005).

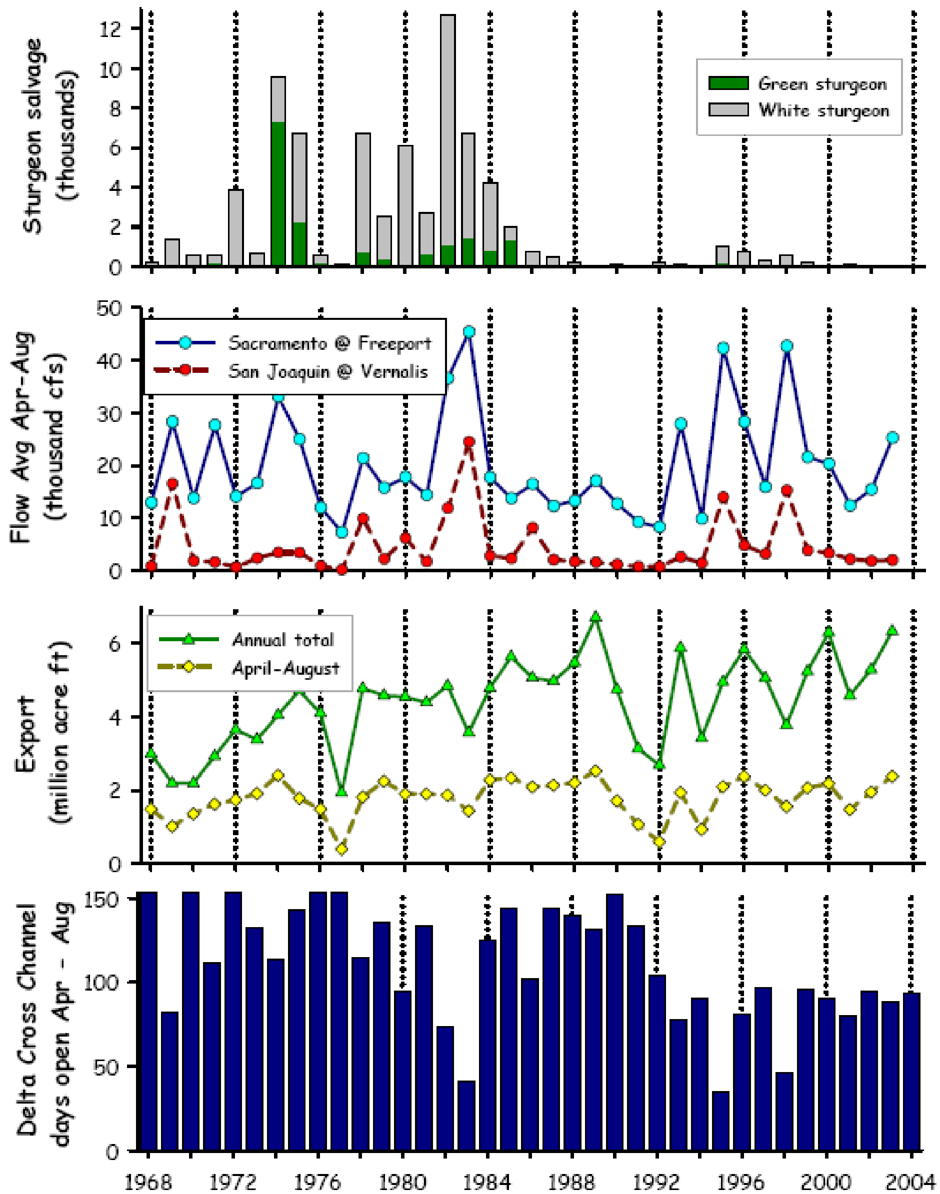

Figure 8-13. Annual patterns in sturgeon salvage, river flow, export volume, and Delta Cross Channel operation, 1968-2004 (Beamesderfer 2005). The April-August period corresponds to the timing of downstream dispersal of juvenile white and green sturgeon from areas of the Sacramento River where they were spawned (Beamesderfer 2005).

Factors that May Influence Abundance and Distribution

NMFS' threatened listing determination of the Southern DPS of green sturgeon was made after consideration of the best available information regarding "loss of historical habitat, the concentration of the spawning population into a single location, the trend in the salvage data, and the cumulative risk from a number of different threats in the Sacramento River and Delta Systems" (71 FR 17758). The following narrative provides a description of potential threats that may have contributed to the decline of green sturgeon in the Southern DPS according to categories identified by NMFS.

Fish Passage

A principal threat to green sturgeon is the reduction of spawning areas as the result of impassible barriers, primarily Keswick Dam on the Sacramento River and Oroville Dam on the Feather River, that block access to historic spawning habitat for anadromous species (Lindley et al. 2004; NMFS 2005). The Feather River is likely to have supported significant spawning habitat for green sturgeon in the Central Valley in the past (DFG 2002). Green sturgeon adults have been observed periodically in the Feather River (FWS 1995; Beamesderfer et al. 2004) and there may be sufficient habitat above Oroville Dam for occupation by sturgeon in the upstream reaches of the Feather River. Sufficient conditions may also be present in the San Joaquin River upstream to Friant Dam, and in the tributaries such as Stanislaus, Tuolumne, and Merced rivers upstream to their respective dams, although it is unknown whether green sturgeon ever used the San Joaquin River and its tributaries for spawning (Beamesderfer et al. 2004).

Potential barriers to adult migration for green sturgeon in the Central Valley include structures such as the RBDD, Sacramento Deep Water Ship Channel locks, Fremont Weir, Sutter Bypass, and DCC gates on the Sacramento River, and Shanghai Bench and Sunset Pumps on the Feather River during low flow periods (70 FR 17386). The RBDD serves as a migration barrier for sturgeon when the gates are closed (FWS 1995). Adult sturgeon can migrate past RBDD when gates are raised between mid-September and mid-May to allow passage for winter-run Chinook salmon and other migratory fish species. However, tagging studies by Heublein et al. (2006) found that, when the gates were closed, a substantial portion of tagged adult green sturgeon failed to use fish ladders at RBDD and were therefore unable to access spawning habitats upstream. A set of locks at the end of the Sacramento River Deep Water Ship Channel at the connection with the Sacramento River "blocks the migration of all fish from the deep water ship channel back to the Sacramento River" (DWR 2003).

Green sturgeon are likely to use the same migratory routes as Chinook salmon. DCC gate closures are required during the winter and early spring months when sturgeon are migrating (February-May), completely blocking migration through the central Delta. Upstream migrating adult Chinook salmon are known to use the DCC as a migratory pathway when the gates are open and Sacramento River water flows into the Mokelumne and San Joaquin rivers (Hallock et al. 1970). It is possible that attraction to this diverted water causes migration delays and straying of green sturgeon, as it does to Chinook salmon, by providing false migration cues (CALFED Science Program 2001; McLaughlin and McLain 2004).

Shasta and Keswick Dams

Reclamation completed Shasta Dam in 1945 and Keswick Dam in 1950. These dams currently block any potential access of sturgeon into the upper Sacramento system. NMFS (2006) concluded that Keswick Dam did block access to assumed historic spawning grounds although the historical upstream extent of green sturgeon distribution is unknown.

Red Bluff Diversion Dam (RBDD)

RBDD was constructed in 1964. RBDD historically blocked migration into a portion of the upper Sacramento River. Green sturgeon are unable to pass upstream from RBDD when the gates are lowered to divert irrigation flows into adjacent canals. Before 1986, the gates were closed year-round. This means that there was a 22-year period when there was complete blockage of spawning habitat above RBDD. After 1993, gates have been open from September 15 through May 14 for passage of winter-run Chinook salmon. The gates of the RBDD are in during the last third of the spawning period of Southern DPS green sturgeon. A draft EIS for RBDD fish passage improvements estimates that closure of the gates results in a 65 percent reduction in green sturgeon blockage to upstream habitat based on adult migration timing (CH2MHill 2002).

Figure 8-14. Historical patterns of gate operations at Red Bluff Diversion Dam.

Optimal spawning temperatures and spawning substrate exist for sturgeon in the Sacramento River well above and well below RBDD. Southern DPS green sturgeon are known to regularly spawn above and below RBDD. Significant natural recruitment of Southern DPS green sturgeon was reported during the 22 year period when the RBDD gates were closed year-round (NMFS 2005) which suggests that at least some some adult green sturgeons attempting to pass through the dam when the gates were closed, were able to spawn successfully downstream.

Following any emergency closure for water delivery purposes prior to May 15 of any year, the 2004 OCAP Biological Opinion (NMFS 2004) prescribed a minimum 5 day gate opening prior to June 15 to benefit upstream migration of Spring-run Chinook salmon. Reclamation implemented this emergency gate closure for the first time in 2007 (Reclamation 2007b).

On May 15, 2007, Reclamation staff discovered 5 to 8 adult Southern DPS green sturgeon dead at or below RBDD (FWS 2007a). A total of 12 dead green sturgeon were subsequently recovered. Several adult sturgeon were actually found stuck under the RBDD gates. A subsequent necropsy determined that at least one was killed by a RBDD gate (FWS 2007b). It is possible that this action, although designed to benefit salmon, may have inadvertently degraded passage and habitat conditions for Southern DPS green sturgeon in proximity to RBDD. Following the first reports of Southern DPS green sturgeon deaths, the salmon migration monitoring operations of the FWS were adjusted and the eleven gate openings were either increased to a 1 foot minimum or to full closure to avoid potential impingement of sturgeon against openings that were too small to provide for their safe downstream passage. Reclamation is only aware of one other Southern DPS green sturgeon carcass being reported in the past 40 years of operation of the RBDD (Reclamation 2007b).

Delta Cross Channel (DCC) Gates Operations

The DCC is a controlled diversion channel located in the northern Delta between the Sacramento River and Snodgrass Slough, a tributary to the Mokelumne River. Reclamation operates the DCC gates to improve the transfer of water from the Sacramento River to the central Delta and export facilities at the Banks and Jones Pumping Plants. To reduce scour in the channels on the downstream side of the DCC gates and to reduce potential flood flows that might occur from diverting water from the Sacramento River into the Mokelumne River system, the radial gates are closed whenever flows in the Sacramento River at Freeport reach 25,000 to 30,000 cfs on a sustained basis. Flows through DCC gates are determined by Sacramento River stage and are not affected by export rates in the south Delta.

The DCC gates can be closed by Reclamation for the protection of fish, provided that water quality is not a concern in the Central or South Delta. From February 1 through May 20, the SWRCB D-1641 requires that the DCC gates remain closed for the protection of emigrating juvenile Chinook salmon in the Sacramento River. An optional gate closure up to 45 days can be requested by the fish agencies during the November through January period and 14 days during the May 21 through June 15 period. The timing and duration of these closures is determined by Reclamation in consultation with FWS, DFG and NMFS.

When the DCC gates are open, juvenile Southern DPS green sturgeon may pass through and enter into the central Delta, which is generally regarded as being lower habitat quality than the western Delta. However, as juvenile green sturgeons are strong swimmers by the time they get into the Delta, and are roaming and feeding about the Delta for one to two years, they possess the ability behaviorally select or avoid habitats within the Delta as desired.

It is possible that water leakage though the DCC gates when closed might serve as a false attractant to green sturgeon adults entering the Delta and moving through the Mokelumne River system from the San Joaquin River side. The DCC gates are closed during the upstream migration period for green sturgeon, thus fish could be blocked by the DCC from entering the mainstem Sacramento River at Walnut Grove.

South Delta Temporary Barriers

The South Delta Temporary Barriers Program (TBP) was initiated in 1991. Its objectives are the short-term improvement of water conditions (water quality and elevation) for the south Delta and agricultural diversions, for the improvement of protection for San Joaquin River salmon, and for the development of data for the design of permanent gates. The program involves the seasonal installation of four barriers—one each on Middle River, Grant Line Canal, and Old River and a fish control barrier at the head of Old River. The barriers are a combination of rock placed into the main channel bed at each location along with overflow weirs and several gated culverts. These barriers are installed in the spring and removed in the fall.

When the barriers are in, Southern DPS green sturgeon within the barriers are trapped in the south Delta, where the habitat is generally regarded as low quality. When the barriers are removed, the Southern DPS green sturgeon are able to migrate out of the south Delta. The TBP continues to be implemented on an annual basis as an interim solution to water levels and circulation until a permanent solution can be implemented.

Suisun Marsh and Salinity Control Gates

DWR operates the Suisun Marsh Salinity Control Gates (SMSCG) to maintain water quality standards set by the SWRCB in D-1641 and the Suisun Marsh Preservation Agreement. The non-operation configuration of the SMSCG from June through August and any period during September through May when the gates are not in operation to meet salinity standards typically consists of the flashboards installed, but the radial gate operation is stopped and held open. Flashboards will be removed if it is determined that salinity conditions at all trigger stations would remain below standards for the remainder of the control season through May 31.

It is possible for young sturgeon to become entrained into Montezuma Slough and Suisun Marsh when the SMSCG is fully operational. Fish may enter Montezuma Slough as they emigrate from the Sacramento River during the fall when the gates are open to draw freshwater into the marsh and then may not be able to move back out when the gates are closed. However, the degree to which movement of green sturgeon is constrained is unknown. In addition, it is possible upstream passage of adults could be influenced as adult green sturgeon may pass through the marsh channels from December through May when their migration into spawning grounds could potentially be delayed. The affects of entrainment on juvenile green sturgeon at RRDS screen intakes is unknown as screening standards for green sturgeon are currently unidentified.

Feather River

Oroville and Thermalito diversion dams currently block any potential sturgeon access into the upper portion of the Feather River. Oroville Dam construction began in 1957 and was completed in 1968. Constructed between 1963 and 1968, the Thermalito Diversion Dam and Pool are located about 4.5 miles downstream from Oroville Dam. NMFS (2006) concluded that Oroville blocked access to assumed historic spawning grounds although the historical upstream extent of green sturgeon distribution is unknown and dams were constructed upstream prior to construction of Oroville Dam.

Other potential natural and man-made passage barriers in the lower Feather River may limit movement of sturgeon into the Feather River during low-flow years (Beamesderfer 2004). Potential barriers include Shanghai Bench (RM 24.5), a natural geologic feature; an artificial rock weir structure at Sunset Pumps (RM 38.5), and Steep Riffle (RM 61), a natural feature. The extent of these sites as a barrier is not well understood since recently collected anecdotal information and data indicates that sturgeon are found upstream of these potential barriers at the

Thermalito Outlet almost yearly (DWR, unpublished data). Under low flow conditions (~2000 cfs), the waterfalls at Shanghai Bench measure approximately 3 - 5 feet in vertical height, stretch across much of the main river channel and exhibit velocities estimated at greater than 3.3 fps (Niggemyer and Duster 2003). The waterfall at Shanghai Bend becomes a riffle at approximately 5100 cfs and may become passable to sturgeon (DWR 2005d). The rock structure at Sunset Pumps exhibits a 2 - 3 foot waterfall and a 4-foot wide slot with water velocities estimated at greater than 5 fps while flows are around 2000 cfs. While it was originally determined that sturgeon likely could not pass this area at low flows (Niggemyer and Duster 2003), recent data from white sturgeon passage studies indicate white sturgeon can pass through velocities up to 8.3 fps (Anderson et al. 2007c). Passage of Sunset Pumps by sturgeon during flows around 10,000 cfs is unlikely as velocities within the slot were estimated at around 10-15 fps (Niggemeyer and Duster 2003). However, it has been estimated that when flows reach about 15,000 cfs, they over-top the rock structure and passage seems likely. Steep Riffle represented the most reasonable passable potential barrier during low-flow and high-flow conditions. Passage determinations at each of the potential migration barriers in the lower Feather River would continue to be speculative without a greater understanding of sturgeon migration patterns and physiologic limitations (DWR 2003). Currently, studies are in place to attempt to gather this information in order to better describe the impacts that sturgeon may face in the Feather River.

Water Diversions

Larval sturgeon are susceptible to entrainment at water diversion facilities, primarily located on the Sacramento River near spawning and juvenile rearing habitat, as a result of their migratory behavior within the water column. Herren and Kawasaki (2001) documented up to 431 diversions from the Sacramento River between Sacramento and Shasta Dam. Entrainment information regarding larval and post-larval individuals of the Southern DPS of green sturgeon is unreliable, as field identification of green sturgeon larvae is difficult. FWS staff are working on identification techniques and are optimistic that green sturgeon greater than 40 mm can be identified in the field (Poytress 2006). Captures reported by GCID are not identified to species, but are assumed to primarily consist of green sturgeon because white sturgeon are known to spawn downstream (Schaffter 1997). Although screens at GCID diversion satisfy both the NMFS and DFG screening criteria for salmonids, the effectiveness of these criteria is unknown for sturgeon. Low numbers of green sturgeon have also been identified and entrained at the Red Bluff Research Pumping Plant (Borthwick et al. 1999).

In the Feather River, there are eight large diversions greater than 10 cfs and approximately 60 small diversions of one to 10 cfs between the Thermalito Afterbay outlet and the confluence with the Sacramento River (FWS 1995). Based on potential entrainment problems of green sturgeon elsewhere in the Central Valley and the presence of multiple screened and unscreened diversions on the Feather River, it is assumed that entrainment at water diversions on the Feather River are a possible threat to juvenile green sturgeon.

Presumably, as green sturgeon juveniles grow, they become less susceptible to entrainment as their capacity to escape diversions improve. The majority of North American green sturgeon captured in the Delta and San Francisco Estuary are between 200 and 500 mm in length (DFG 2002). Herren and Kawasaki (2001) inventoried water diversions in the Delta finding a total of 2,209 diversions of various types, only 0.7 percent of which were screened. The majority of these diversions were between 12 and 24 inches (305 and 710 mm) in diameter, which is not likely a great threat to larger juvenile sturgeon. The largest diversions recorded were those of the CVP and SWP facilities in the southern Delta, which has historical data of captures (DFG 2002).

Entrainment at Unscreened Water Diversions

There are over 2,600 diversions of water in the Sacramento River and Delta. California State law requires all new water diversions to be screened. There is no commercial or scientific data to indicate what the risks are for adult green sturgeon to be entrained at unscreened diversions. However, as green sturgeon are bottom oriented, strong swimmers, and grow rapidly in their first year, Reclamation assumes that green sturgeon are most at risk in their first month or two of life and unscreened diversions in the upper Sacramento River have the greatest potential for entrainment. Most diverters in the upper Sacramento River have pre-CVP water rights and have been diverting water for decades. Approximately 70 percent of all diversions over 250 cubic feet per second (cfs) are now screened. Most of the smaller diversions, particularly the ones in the Delta, are too small to pose a risk to juvenile sturgeons. There is no evidence to indicate that sturgeon are entrained by the operations of the Contra Costa Canal (Reclamation 2006).

Impingement or Entrainment at Screened Diversions of Water

Studies have determined that fish screens operating to delta smelt velocity criteria (0.1 feet per second (fps)), salmon velocity criteria (0.33 fps), or even faster velocities (0.5 fps) were also protective to juvenile Southern DPS green sturgeon (30 mm or larger) (Swanson et al. 2004). Fish screens are not effective with smaller openings in the screen mesh (O'Leary, Personal Communication 2006).

Southern DPS green sturgeon are vulnerable to impingement or entrainment at screened diversions when they are less than 30 mm in length. Larger fish cannot pass through typical fish screen openings, and are also better able to swim and therefore avoid contact. Green sturgeon are larger than 30 mm after 15 to 21 days of age, and in addition they remain hidden in spaces between rocks for their first 10 days after hatching. Therefore green sturgeon are expected to be most vulnerable to impingement and entrainment at screened diversions for only 5 to 11 days. Figure 8-15 shows that half of the green sturgeon caught at the RBDD are greater than 30 mm in length, and Figure 8-16 shows that all of the green sturgeon caught at the GCID are greater than 30 mm in length. As with unscreened diversions discussed above, NMFS 2006 concluded that the potential threat of these diversions is in need of study.

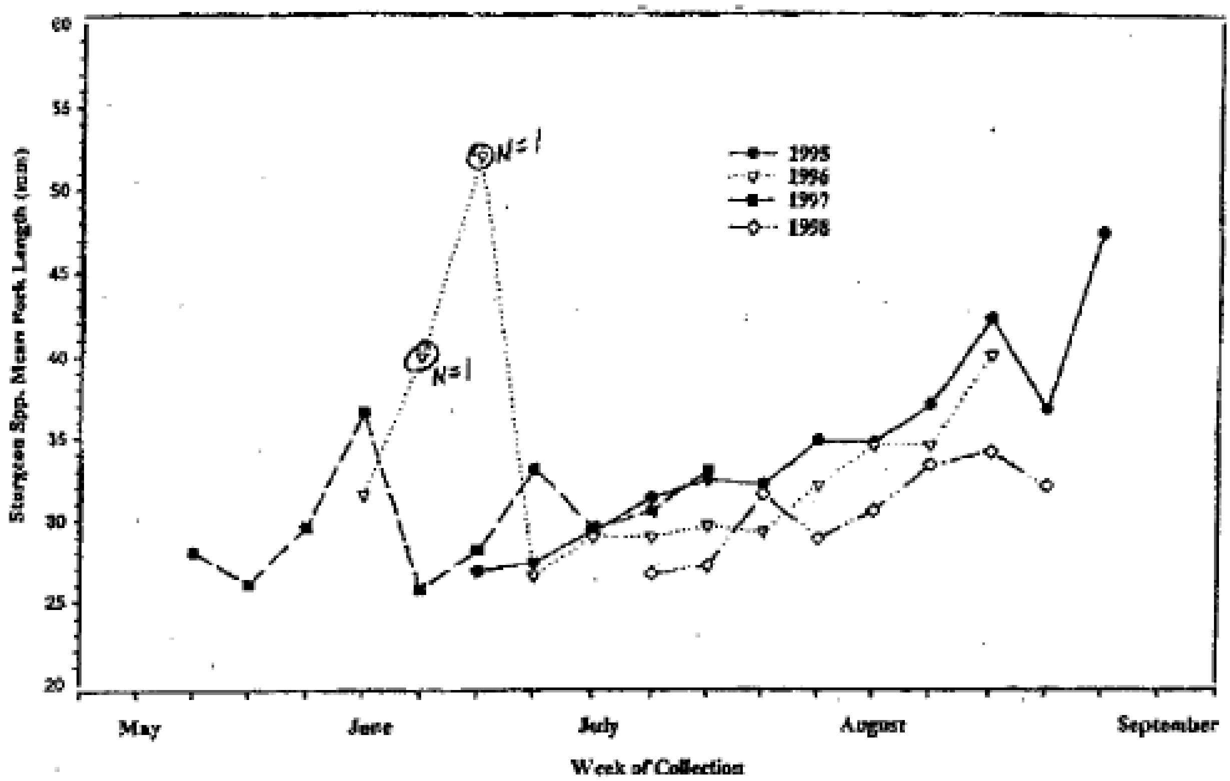

Figure 8-15. Mean fork lengths in mm of green sturgeons captured weekly by rotary screw traps at the Red Bluff Diversion Dam from 1995 to 1998 (DFG 2002).

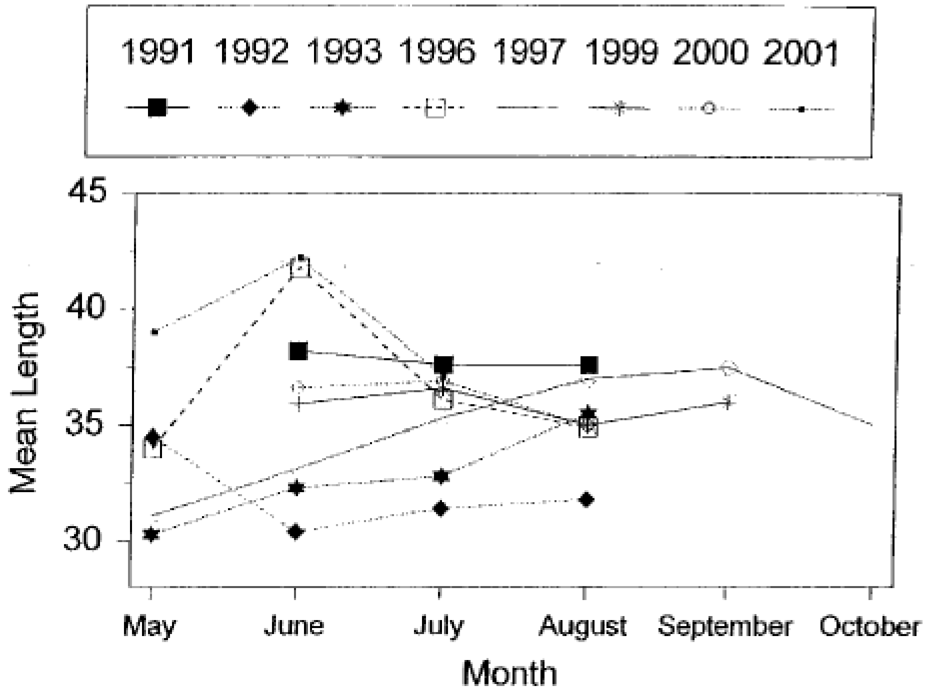

Figure 8-16. Monthly mean lengths in mm of sturgeon caught by the Glenn Colusa Irrigation District rotary screw trap from 1999 to 2001 (DFG 2002).

ACID Diversion Dam

The Anderson Cottonwood Irrigation District (ACID) constructed the Anderson Cottonwood Irrigation District Diversion Dam in 1937. New state of the art fish ladders and screens at ACID's main diversion were installed with funding provided by CALFED via Reclamation (Reclamation and FWS 2004) although ladders were designed for salmon rather than sturgeon passage. No sturgeon passage occurs at ACID when the diversion dam is in place. The availability of favorable spawning and rearing habitat conditions for green sturgeon upstream and downstream from the dam is unknown.

CVP Export Facilities and the Tracy Fish Collection Facility

The Tracy Fish Collection Facility (TFCF), at the intake to the DMC, is designed to intercept fish before they are entrained into the DMC by the Tracy Pumping Plant. Fish are collected and transported by tanker truck to release sites away from the pumps. Adult Southern DPS green sturgeon are rarely observed at the TFCF. In the last 8 years, only one adult (over 2 meters in total length) was found on the TFCF trash rack in spring 2003 (Reclamation 2006b). Adult sturgeon were also periodically reported impinged in the trash racks prior to 2000.

Table 8-2 shows the reliable historic record sturgeon salvage by month, since 1993 when species identifications are considered to be reliable. All other non-sampled fish that enter the facility are collected and transported by tanker truck to downstream Delta release sites.

Table 8-2. Actual salvage of Southern DPS green sturgeon and white sturgeon at the Tracy Fish Collection Facility (Reclamation 2007a). GRN = Southern DPS green sturgeon, WHT = white sturgeon.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	0 grn 0 wht	1 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 2 wht	0 grn 1 wht	0 grn 0 wht	0 grn 3 wht
1994	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 0 wht	0 grn 0 wht
1995	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 3 wht	1 grn 8 wht	0 grn 8 wht	0 grn 14wht	0 grn 9 wht	4 grn 4 wht
1996	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 2 wht	0 grn 0 wht	0 grn 1 wht	1 grn 4 wht	0 grn 1 wht	0 grn 2 wht	2 grn 3 wht	0 grn 1 wht	0 grn 1 wht
1997	0 grn 0 wht	0 grn 0 wht	0 grn 4 wht	1 grn 1 wht	1 grn 0 wht	2 grn 1 wht	0 grn 1 wht	0 grn 1 wht	1 grn 2 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht
1998	0 grn 2 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 1 wht	0 grn 6 wht	1 grn 8 wht	1 grn 3 wht	0 grn 0 wht
1999	0 grn 1 wht	0 grn 1 wht	0 grn 1 wht	0 grn 0 wht	1 grn 1 wht	0 grn 1 wht	0 grn 2 wht	0 grn 2 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2000	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2001	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 1 wht	0 grn 0 wht	1 grn 0 wht	0 grn 0 wht	1 grn 0 wht
2002	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2003	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2004	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht
2005	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2006	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 0 wht	9 grn 0 wht	2 grn 0 wht	3 grn 0 wht	5 grn 1 wht	7 grn 0 wht	1 grn 0 wht
2007	1 grn 0 wht	0 grn 1 wht	0 grn 2 wht	0 grn 1 wht								

State Water Project Export Facilities and Skinner Fish Protection Facility

The Skinner Fish Protection Facility (SFPF) located between Banks and CCF, intercepts fish, which are collected and transported by tanker truck to downstream release sites. This facility uses behavioral barriers to guide targeted fish into holding tanks for subsequent transport by truck to release sites within the Delta. Table 8-3 shows the reliable historic record of SWP sturgeon salvage, by month, between 1993 and 2007. All other non-sampled fish passing through the facility are collected and transported by tanker truck to Delta release sites.

Table 8-3. Actual salvage of Southern DPS green sturgeon and white sturgeon at the Skinner Fish Protection Facility (Reclamation 2007a). GRN = Southern DPS green sturgeon, WHT = white sturgeon.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	3 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 0 wht	0 grn 1 wht	2 grn 2 wht	0 grn 0 wht
1994	0 grn 0 wht	1 grn 2 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
1995	2 grn 5 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 6 wht	3 grn 6 wht	0 grn 2 wht	0 grn 14wht	1 grn 1 wht	0 grn 0 wht
1996	0 grn 31wht	0 grn 5 wht	2 grn 3 wht	0 grn 2 wht	0 grn 0 wht	2 grn 2 wht	0 grn 1 wht	0 grn 2 wht	2 grn 1 wht	0 grn 2 wht	0 grn 5 wht	0 grn 4 wht
1997	0 grn 1 wht	0 grn 0 wht	0 grn 6 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	1 grn 1 wht	0 grn 1 wht	0 grn 1 wht	0 grn 1 wht
1998	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	4 grn 2 wht	2 grn 2 wht	1 grn 0 wht	0 grn 2 wht	0 grn 1 wht
1999	0 grn 0 wht	2 grn 1 wht	0 grn 1 wht	0 grn 3 wht	0 grn 0 wht	0 grn 0 wht	0 grn 2 wht	0 grn 2 wht	1 grn 1 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht
2000	0 grn 0 wht	3 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	1 grn 1 wht	1 grn 1 wht
2001	0 grn 0 wht	0 grn 1 wht	1 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	4 grn 1 wht
2002	0 grn 0 wht	0 grn 0 wht	2 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 1 wht
2003	1 grn 0 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2004	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2005	2 grn 0 wht	0 grn 0 wht	0 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	2 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht
2006	1 grn 1 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	0 grn 0 wht	1 grn 2 wht	0 grn 1 wht	2 grn 0 wht	0 grn 1 wht	0 grn 1 wht	2 grn 0 wht
2007	0 grn 0 wht	0 grn 1 wht	1 grn 1 wht									

Mirant's Pittsburg and Contra Costa Power Plants

Power plant operations potentially affect fish by entraining and impinging them to the points of cooling water diversion, exposure to chlorine from cleaning processes, and increasing water temperatures with discharged cooling flows. Studies done in 1976 and 1991 (DWR 2005c), which did not report any sturgeon, found greater numbers of some fish species near thermal discharge sites, but no evidence for direct mortality of striped bass and no thermal blockage of migratory species including Chinook salmon, striped bass or American shad. Studies done in 1991 (DWR 2005c), which did not report any sturgeon, were inconclusive as to the effects of chlorination for control of condenser slime. These studies also indicated no entrainment or impingement of green sturgeon.

Low Flows

NMFS 2006 states that “DFG and FWS found a strong correlation between mean daily freshwater outflow (April to July) and white sturgeon year class strength in the Sacramento-San Joaquin Estuary (these studies primarily involve the more abundant white sturgeon; however, the threats to green sturgeon are thought to be similar), indicating that insufficient flow rates are likely to pose a significant threat to green sturgeon."

High temperatures caused by lower flows in rivers and the Delta may have a negative effect on sturgeon populations. DFG (1992) and FWS (1995) found a strong correlation between mean daily temperature (April to July) and white sturgeon year-class strength from the Sacramento River. The Shasta Temperature Control Device began operating in 1997, but storage limitations may limit the ability of Shasta Dam releases to regulate temperatures during drier water years. DFG (1992) and FWS (1995) also found a strong correlation between mean daily freshwater outflow from the Sacramento-San Joaquin watershed and year-class strength in the estuary. It should be noted that flow and temperature are correlated, and the DFG and FWS studies were conducted prior to temperature control device installation on Shasta Dam; therefore, it is difficult to quantify flow effects on juvenile production independent of temperature.

The lack of flow in the San Joaquin River from dam and diversion operations and agricultural return flows contribute to higher temperatures in the mainstem San Joaquin River, offering less water to keep temperatures cool for sturgeon, particularly during late summer and fall. Whether direct or indirect, the effects of flow on green sturgeon are not well understood but likely play an important role in population performance, which is why lows flows are documented as a potential threat in NMFS' 2002 and 2005 status reviews (Adams et al. 2002; NMFS 2005) and the Federal register (70 FR 17386; 71 FR 17757).

Water Temperature

Water temperatures greater than 63ºF can increase mortality of sturgeon eggs and larvae (PSMFC 1992). Moderated stream temperatures in spawning and egg incubation areas are critical as temperatures above 68˚F are lethal to green sturgeon embryos (Cech et al. 2000). Temperatures near RBDD on the Sacramento River historically occur within optimum ranges for sturgeon reproduction; however, temperatures downstream, especially later in the spawning season, were reported to be frequently above 63ºF (USFWS 1995). High temperatures in the Sacramento River from February to June no longer appear to be a concern as temperatures in the upper Sacramento River are actively managed for Sacramento River winter-run Chinook salmon. The Shasta temperature control device installed at Shasta Dam in 1997 appears to maintain cool water conditions below the dam.

As shown on Figure 8-17, a considerable reach of the Sacramento River maintains suitable spawning temperatures for the Southern DPS green sturgeon. From river mile 90 to river mile 160, suboptimal spawning temperatures of 64-68°F occur on average. Optimal spawning temperatures occur from river mile 160 to river mile 302. During the first two-thirds of the spawning season, when the RBDD gates are out, Southern DPS green sturgeon have access to 70 river miles of suboptimal spawning temperatures and 140 river miles of optimal spawning temperatures. During the last one-third of the spawning season, when the RBDD gated are in, Southern DPS green sturgeon have access to 70 river miles of suboptimal spawning temperatures and 78 river miles of optimal spawning temperatures. Note that this description describes the number of available river miles but it is unclear how much actual spawning habitat exists in each portion of the river.

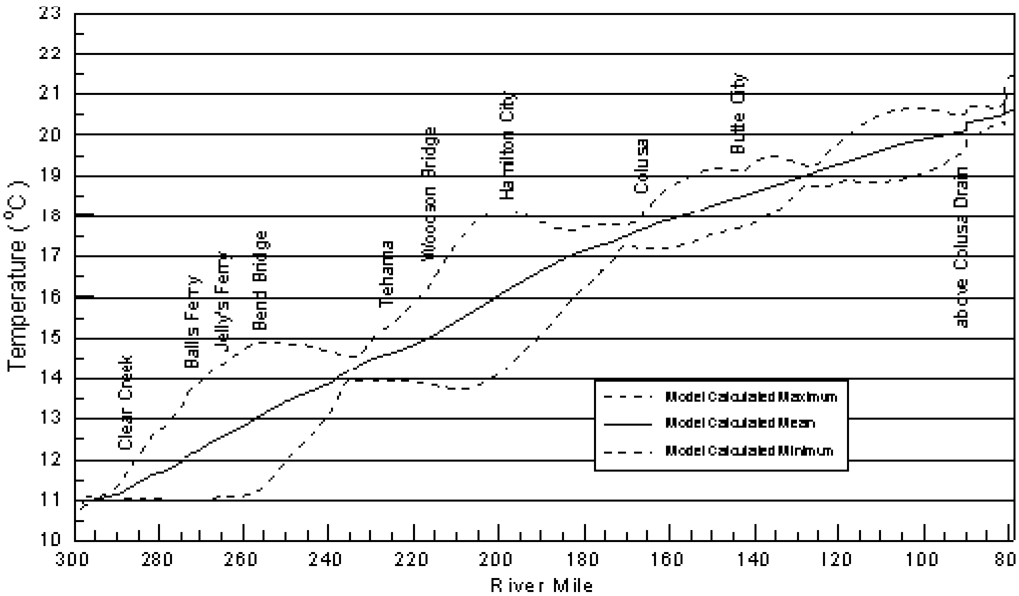

Figure 8-17. Modeled temperatures in the Sacramento River below Keswick Dam (Orlob and King 1997).

NMFS (2006) states that "Elevated water temperature is likely no longer a problem in the Sacramento River with the installation of the Shasta Dam Temperature Control Device in 1997." However, green sturgeon reproduction before 1997, when the Shasta Dam Temperature Control Device was installed, may well have been adversely affected by temperature. There has been a great deal of fishery management emphasis on keeping the Upper Sacramento River cool enough for salmonids eggs (<57°F). For Southern DPS green sturgeon, 57°F is well below their upper limit of optimal temperature for egg development of 63 to 64°F (Van Eenennaam et al. 2005). Therefore, in the Sacramento River, Southern DPS green sturgeons are not limited by a lack of suitable spawning temperatures nor are they likely threatened by drought induced increases in water temperatures.

Water temperatures in the Feather River appear adequate for spawning and egg incubation, contrary to previous concerns that releases of warmed water from Thermalito Afterbay are one reason neither green nor white sturgeon are found in the river in low-flow years (DFG 2002, SWRI 2003). In some years, water temperatures downstream of the Thermalito Outlet are inadequate for spawning and egg incubation, which has been suggested as a reason why green sturgeon are not found in the river during low flow years (DWR 2007). However, post-Oroville Dam water temperatures are cooler than historic river temperatures during the summer months when early life stages are likely to be present in the lower Feather River (DWR 2005a). Prior to the construction of the Oroville Dam, water temperatures in the Feather River at Oroville averaged 65-71°F from June through August for the period of 1958-1968 (CDWR 2004). After Oroville Dam construction, water temperatures in the Feather River at the Thermalito Afterbay averaged 60-65°F from June through August for the period of 1993-2002 (CDWR 2004). In addition, modeling results indicate that under existing conditions, water temperatures several miles downstream of the Thermalito Outlet would average 66ºF or less in 80 percent of all days in July (DWR 2005a).

NMFS states “An effective population of spawning green sturgeon (i.e., a population that is contributing offspring to the next generation) no longer exists in the Feather River and was likely lost due to … thermal barriers associated with the Thermalito Afterbay Facility.” (71 FR 17762). However, Spring-run Chinook salmon regularly hold below and pass upstream of the Thermalito Outlet (CDWR 2005b) suggesting that the outlet of the Thermalito Afterbay does not represent a complete thermal barrier to coldwater species. Similarly, most anecdotal observations of Southern DPS green sturgeon in the Feather River come from the pool below the Thermalito Outlet (DWR 2007). The availability of cold water and deep holding pools further upstream suggests that Southern DPS green sturgeon are selecting the habitat found at the outlet for holding (and possible spawning during some years) rather than avoiding it as a thermal barrier.

Temperatures in the lower San Joaquin River continually exceed preferred temperatures for sturgeon migration and development during spring months. Temperatures at Stevenson on the San Joaquin River near the Merced River confluence on May 31, 2000-2004 (spawning typically occurs during Apr-June) ranged from 77 to 82ºF (California Data Exchange Center, preliminary data). Juvenile sturgeon are exposed to increased water temperatures in the Delta during the late spring and summer due to the loss of riparian shading, and by thermal inputs from municipal, industrial, and agricultural discharges. High water temperatures on the San Joaquin River and in the Delta are likely to deter spawning in these regions.

Contaminants

No specific information is available on contaminant loads or impacts of contaminants on green sturgeon. The difference in distribution of green and white sturgeon (ocean migrants vs. estuarine inhabitants) probably makes green sturgeons less vulnerable than white sturgeon to bioaccumulation of contaminants found in the estuary. NMFS 2006 states that “we conclude that some degree of risk from contaminants probably occurs for green sturgeon.

Environmental stress as a result of poor water quality can lower reproductive success and may account for low productivity rates of green sturgeon (Klimley 2002). High levels of trace elements can also decrease sturgeon early life-stage survival, causing abnormal development and high mortality in yolk-sac fry at concentrations of only a few parts per billion (FWS 1995). Water discharges from Iron Mountain Mine have affected survival of fish downstream of Keswick Dam, and limited availability of dilution flows cause downstream copper and zinc levels to exceed salmonid tolerances. Although the impact of trace elements on green sturgeon production is not completely understood, negative impacts are suspected (71 FR 17763).

Researchers documented a sharp increase in pesticide contamination in the mid-1970s with the increase in use of rice pesticides (FWS 1995). It is thought that pesticide use likely represents a source of risk for green sturgeon because negative effects have been observed in other anadromous Sacramento River species (70 FR 17392).

The Aquatic Pesticide Monitoring Program evaluations, funded by the California State Water Resources Control Board, suggested that potential effects of aquatic herbicides on fish in the Delta are not likely to be significant for most herbicides in use, with worst case scenario modeling and studies conducted over three years showed little indication of short-term and no long-term toxicity of aquatic herbicide applications (Siemering 2005). In addition, according to NMFS 2005, the decline of Southern DPS green sturgeon occurred in 1986, while large scale treatment of the Delta with herbicides to control water hyacinth (*Eichhornia crassipes*) began in 1982 and *Egeria densa* did not commence until 2001.

Little is known about green sturgeon dietary intake. The gut contents of the only green sturgeon recently examined from the Southern DPS revealed that it had been feeding on overbite clams (*Corbula*), a nonnative species known to bioaccumulate selenium (DFG 2002; Linville et al. 2002). Though the extent of accumulation of contaminants in green sturgeon is unknown, bioaccumulation of toxins in white sturgeon is well documented (Feist et al. 2004; Webb et al. 2004) and likely posses a similar threat to green sturgeon.

Dredging

Hydraulic dredging is a common practice to allow commercial and recreational vessel traffic. Such dredging operations can pose risks to bottom oriented fish such as sturgeon. For example, studies by Buell (1992 as cited in NMFS 2007) reported approximately 2,000 white sturgeon entrained in the removal of one million tons of sand from the bottom of the Columbia River at depths of 60-80 feet. In addition, dredging operations can elevate toxics such as ammonia, hydrogen sulfide, and copper (NMFS 2006). Other factors include bathymetry changes and acoustic impacts (NMFS 2006).

Harvest

As long-lived, late maturing fish that spawn periodically, green sturgeon are particularly susceptible to threats from overfishing (Musick 1999). Green sturgeon are regularly caught in the sport, commercial, and tribal fisheries, particularly in Oregon and Washington commercial fisheries (Beamesderfer 2005). With the exception of a Klamath River fishery, green sturgeon are not targeted by fisheries but are caught incidental to harvest of white sturgeon and salmon. Harvest of mixed green sturgeon populations in Oregon and Washington fisheries has steadily declined from a peak of over 8,000 fish per year in 1986 to less than 1,000 fish per year since 2001 (Figure 8-18). This reduction is not due to declining catch-per-effort but is in response to market conditions, regulation changes, and changing fisheries for other species (ODFW 2005b). Limited information suggests no negative or positive population abundance trends in Oregon populations of Southern DPS green sturgeon (ODFW 2005a).

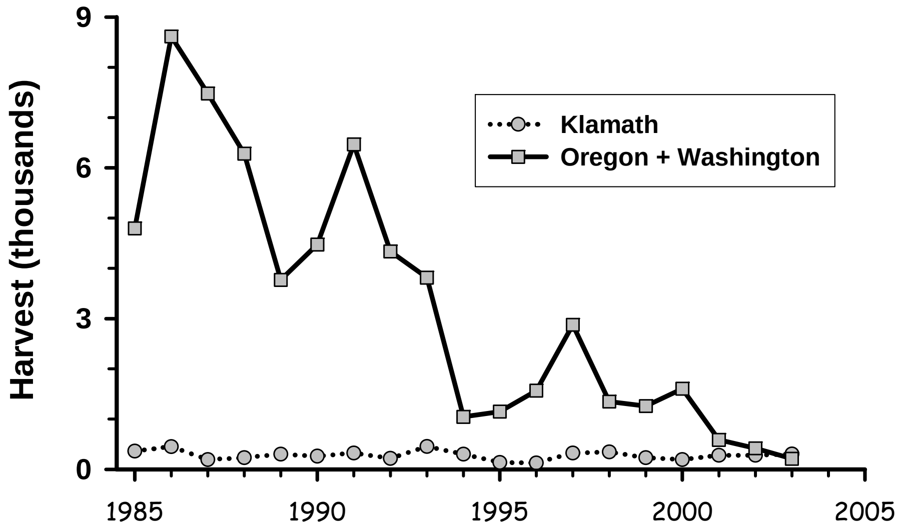

Figure 8-18. Recent annual harvest of green sturgeon (NMFS 2005). Klamath includes Yurok and Hoopa subsistence fishery harvests. The Oregon and Washington total includes sport and commercial fishery harvests from ocean and estuary fisheries including the Columbia River, Willapa Bay, and Greys Harbor. Figure from Beamesderfer et al. (2007).

The largest annual landings occurred in the bays and estuaries of Oregon and Washington (Adams et al. 2002), areas where green sturgeon are known to congregate in the spring and summer (Lindley et al. 2008). Total commercial harvest of green sturgeon in the Columbia River Estuary between 1985-2001 ranged from 240 to 6,000 fish per year (Adams et al. 2002). During this period, Columbia River fisheries harvested over half of the green sturgeon caught in the northern and Southern DPSs. Washington coastal fisheries took approximately 28 percent of the total catch. The bulk of Washington harvest occurred in the Willapa Bay and Grays Harbor areas. About 8 percent of the catch was recorded in California tribal and Oregon sport and commercial fisheries. Harvest numbers in the Klamath River have remained constant, but accounted for a larger percentage of the total catch due to harvest reductions in the Columbia River, Grays Harbor and Willapa Bay fisheries (NMFS 2005).

Green sturgeon are primarily captured incidentally in California by sport fisherman targeting the more desirable white sturgeon, particularly in San Pablo and Suisun Bays (Emmett et al. 1991). New regulations mandate that no green sturgeon can be taken or possessed in California (DFG 2007). If green sturgeon are caught incidentally and released while fishing for white sturgeon, it must be reported to DFG. Sport fishing catch has been reduced through time; however, it is not known if this is a result of reduced abundance, changed fishing regulations, or other factors. DFG (2002) indicates high sturgeon vulnerability to the sport fishery in areas where sturgeon are concentrated, such as the Delta to San Pablo Bay area in late winter and the upper Sacramento River during the spawning migration. Further north, a high proportion of green sturgeon present in the Columbia River, Willapa Bay, and Grays Harbor (as much as 80 percent in the Columbia River) may be from the southern DPS (DFG 2002; Israel 2006; Lindley et al. 2008).

Historical trends in green sturgeon abundance can be at least partly inferred from white sturgeon harvest records (Figure 8-19). Large white sturgeon commercial fisheries developed in San

Francisco Bay and the Columbia and the Fraser rivers during the late 1800s for previously-unexploited white sturgeon populations. Fisheries collapsed within a few years as sturgeon were rapidly harvested at rates far in excess of sustainability (FWS 1993). Protective regulations were enacted following the fishery collapse but populations did not begin to recover for almost 50 years because of the white sturgeon's longevity and delayed maturation. In California, it is unlawful for sturgeon to be taken or possessed for commercial purposes (DFG 2006). Modern harvests have never approached historic levels as fisheries are regulated at more sustainable rates. Green sturgeon were not targeted by excessive white sturgeon fisheries (Beamesderfer 2005, Moyle 2002 and NMFS 2005) but green sturgeon populations were likely depleted as a result of by catch (FWS 1996 and Moyle 2002). Green sturgeon were at least partially buffered from excessive early fisheries by their marine distribution but spawning runs were probably heavily impacted. Like the white sturgeon, green sturgeon probably recovered slowly during the 1900s (Beamesderfer 2005) and gradual recovery is consistent with harvest patterns of green sturgeon in Columbia River fisheries (Figure 8-19).

The longevity of sturgeon is clearly associated with low natural mortality rates beyond the first few years of age. Approximate total annual mortality rates estimated from catch curves for the Klamath River and Columbia River estuary ranged from 8 – 28 percent per year. Total annual rates include both natural and fishing mortalities. The lower rate for Columbia River subadults (8 percent) than for Klamath River adults (19-28 percent) may be due in part to additional fishing mortality during Klamath River spawning migrations although subadults are also subjected to fishing mortality in the Columbia River. These estimates might suggest a natural annual mortality rate of 8 percent or less and fishing mortality rates of 10-20 percent or less on Klamath River adults. These estimates of green sturgeon natural mortality are comparable to those of white sturgeon which typically average 4-16 percent (Beamesderfer 2005).

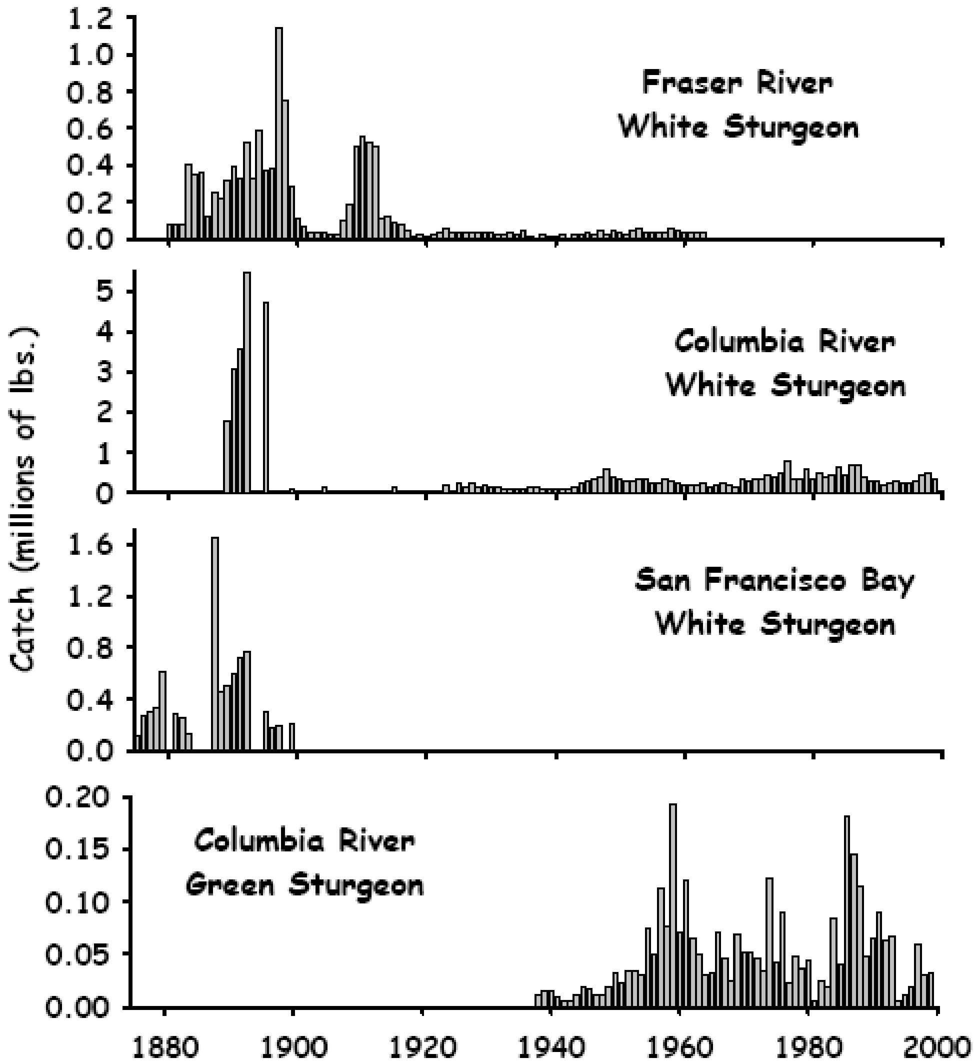

Figure 8-19. Historical yield of white sturgeon in the Fraser River commercial fishery, white sturgeon in the Columbia River commercial and sport fisheries, white sturgeon in San Francisco Bay commercial fisheries and green sturgeon in the Columbia River sport and commercial fisheries (Beamesderfer 2005). Note differences in the scales of the y axes.

Estimates of green sturgeon mortality reflect fishing levels prior to implementation of recent fishery reductions and are uncertain due to untested assumptions of the catch curve estimation method (e.g. constant recruitment and mortality). Fishing mortality rates on Sacramento River green sturgeon are likely to be less than in the Klamath River because there is no terminal fishery on spawners in the Sacramento River. Beamesderfer 2005 estimated white sturgeon exploitation rates in the Sacramento-San Joaquin River Bay-Delta of 1-4 percent per year since a protective slot regulation was implemented for sturgeon in 1990. Green sturgeon exploitation rates within the Sacramento are likely to be less because green sturgeons are less preferred by anglers. Green sturgeon are also subject to incidental fishing mortality in coastal and estuary fisheries of Oregon and Washington.

Illegal harvest of sturgeon is known to occur in the Sacramento River, particularly in areas where sturgeon have become concentrated (e.g., Fremont Weir; M. Marshall, pers comm.), as well as throughout the Bay-Delta. The small population of white sturgeon inhabiting the San Joaquin River experiences heavy fishing pressure, particularly from illegal fishing (FWS 1995). Areas just downstream of Thermalito Afterbay outlet and Cox's Spillway, and several barriers impeding migration, may be areas of high adult mortality from increased fishing effort and illegal harvest. A number of illegal harvest operations for white sturgeon have been discovered in recent years to supply a lucrative caviar market. Green sturgeon caviar is not sought but green sturgeon may be caught incidental to effort targeting white sturgeon. NMFS (2006) states that "DFG has stated that sturgeons are highly vulnerable to fisheries, and the trophy status of large white sturgeon makes sturgeon a high priority for enforcement protection."

Disease and predation

NMFS 2006 states that "we do not believe there is sufficient information to suggest that disease has played an important role in the decline of the Southern DPS." Disease and predation risks are uncertain because little data is available to indicate adverse effects from either of these potential threats. NMFS does, however, acknowledge the potential threat of predation from introduced species such as striped bass (70 FR 17392; 71 FR 17763). More study is needed to determine the magnitude of risk posed by disease and predation in the Southern DPS of green sturgeon.

Little is known about predators of green sturgeon. Smaller fish are undoubtedly taken by various fish and bird predators, although the five lines of sharp, bony scutes along their bodies probably make them less desirable prey than most other species. Predation by pikeminnow, smallmouth bass, and prickly sculpin has been documented for both green and white sturgeon. Sea lions have been observed feeding on adult white sturgeon. Information from the Columbia River suggests that total mortality of green sturgeon is less than for white sturgeon (DFG 2001). NMFS 2006 states that "while predation risk imposed by striped bass on the Southern DPS is uncertain, it likely exists, and additional studies are needed to determine the importance of this threat to the long-term survival of the Southern DPS."

Non-native Invasive Species

Green sturgeon have most likely been impacted by non-native invasive species introductions resulting in changes in trophic interactions in the Delta. Many of the recent introductions of invertebrates have greatly affected the benthic fauna in the Delta. DFG (2002) reviewed many of the recent non-native invasive species introductions and the potential consequences to green sturgeon. Most notable species responsible for altering the trophic system of the Sacramento-San Joaquin Delta include the overbite clam, the Chinese mitten crab, the introduced mysid shrimp *Acanthomysis bowmani*, and another introduced crustaceans, *Gammarus* sp.

Introductions of invasive plant species such as the water hyacinth (*Eichhornia crassipes*) and *Egeria densa* have altered nearshore and shallow water habitat by raising temperatures and inhibiting access to shallow water habitat. *Egeria* forms thick "walls" along the margins of channels in the Delta. This growth prevents juvenile native fish from accessing their preferred shallow water habitat along the channel's edge. Water hyacinth creates dense floating mats that can impede river flows and alter the aquatic environment beneath the mats. Dissolved oxygen levels beneath the mats often drop below sustainable levels for fish due to the increased amount of decaying vegetative matter produced from the overlying mat. Like *Egeria*, water hyacinth is often associated with the margins of the Delta waterways in its initial colonization, but can eventually cover the entire channel if conditions permit. This level of infestation can produce barriers to anadromous fish migrations within the Delta. The introduction and spread of *Egeria* and water hyacinth have created the need for aquatic weed control programs that utilize herbicides targeting these species.

Recent stomach content analysis of white sturgeon from the San Francisco Bay estuary indicates that the invasive overbite clam, Corbula amurensis, may now be a major component of the white sturgeon diet and possibly green sturgeon diets, and unopened clams were often observed throughout the alimentary canal (Kogut 2008). Kogut’s study found that at least 91 percent of clams that passed through sturgeon digestive tracts were alive. Green sturgeon could be affected in a similar manner. This suggests sturgeon are potential vehicles for transport of adult overbite clams and also raise concern about the effect of this invasive clam on sturgeon nutrition and contaminant exposure.