NORTHERN GREEN STURGEON
***Acipenser medirostris* (Ayres)**

Status: High Concern. Very little is known about the current size of the single northern green sturgeon population in California. However, habitat degradation and climate change continue to threaten their status.

Description: Sturgeons, with their large size, subterminal barbeled mouths, lines of bony plates (scutes), and heterocercal (shark-like) tail, are among the most distinctive of freshwater fishes. Green sturgeon have 8-11 scutes in the dorsal row, 23-30 in the lateral rows, and 7-10 in the bottom rows. The dorsal fin has 33-36 rays, and the anal fin 22-28. They are distinguished from white sturgeon, with which they co-occur, by: (1) having one large scute behind the dorsal and anal fins, (2) having scutes that are sharp and pointed, and (3) having barbels that are closer to the mouth than to the tip of the long, narrow snout (Moyle 2002). Their color is olive-green to pale brown, with an olivaceous stripe on each side and scutes that are paler than the body.

Taxonomic Relationships: Green sturgeon were described from San Francisco Bay in 1854 by W. O. Ayres as *Acipenser medirostris*, the only one of three species he described from the Bay that is still recognized. Green sturgeon are tetraploids and have lower fecundity and larger eggs than most other sturgeon (Gessner et al. 2007). The zoogeographic origin of green sturgeon is uncertain; evidence can be mounted for either an Asian or North American ancestry (Artyukhin et al. 2007). The closest relative is the Asian green sturgeon, *Acipenser mikadoi*, described from one poorly preserved specimen (Jordan and Snyder 1906). Schmidt (1950) designated the Asian form (the Sakhalin sturgeon in the Russian literature) as a distinct subspecies, *Acipenser medirostris mikadoi*. DNA measurements show that the Asian form has approximately twice the DNA content of the North American form (Birstein 1993), indicating that *A. mikadoi* is distinct from *A. medirostris*. Recent comparisons found considerable differences in the morphometrics (e.g., snout length measurements) of Asian and North American populations, although meristic counts overlapped one another (North et al. 2002). Birstein (1993) also suggested that there may be considerable genetic difference between California populations of *A. medirostris* and those north of California. Subsequent analysis of North American green sturgeon found genotypic differences between individuals in the Rogue and Klamath rivers from those in the Sacramento River (Israel et al. 2004). This has led to the split of green sturgeon into two Distinct Population Segments (DPS): southern (Sacramento) green sturgeon DPS and northern green sturgeon DPS (Adams et al. 2002, Adams et al. 2007). The National Marine Fisheries Service has designated populations from the Rogue (Oregon), Klamath-Trinity, Eel, and Umpqua (Oregon) rivers as constituting the northern DPS (Adams et al. 2002, Adams et al. 2007). The population in the Sacramento River has been designated as the southern DPS. In this report, the northern DPS of the green sturgeon is referred to as northern green sturgeon.

Life History: The recent recognition of green sturgeon as having two distinct populations (northern and southern DPS) is confounded by the fact that individuals from both populations likely interact in the ocean; therefore, most studies of ecology and behavior do not separate the two forms outside their native rivers. Until the listing of the southern green sturgeon DPS in 2006, the ecology and life history of green sturgeon had received little study because of their generally low abundance and their low commercial and sport-fishing value. Adults are more marine than white sturgeon but can spend up to six months in fresh water (Benson et al. 2007, Erickson et al. 2002).

Spawning populations of northern green sturgeon are confirmed only for the Rogue (Oregon) and Klamath rivers. Green sturgeon migrate up the Klamath River between late February and late July. The spawning period is March-July, with a peak from mid-April to mid-June (Emmett et al. 1991, Van Eenennaam et al. 2006, Benson et al. 2007). Although the spawning period is similar in the Rogue River, post-spawn adults are found in fresh water in both spring and fall (Webb and Erickson 2007). Spawning females are generally larger, heavier, older and in better condition than spawning males (Van Eenennaam et al. 2006, Benson et al. 2007, Erickson and Webb 2007). From 1999 to 2003, the length of spawning females in the Klamath River was 151-223 cm FL, while males measured 139-199 cm FL. In the Rogue River, male and female green sturgeon become sexually mature at 145 cm TL and 166 cm TL, respectively (Erickson and Webb 2007). Most females were 19-34 years old, while males were 15-28 years old. Males are slightly more abundant than females in spawning runs (female:male = 1:1.4). Adults in the Klamath River exhibit four distinct migration patterns characterized by varying lengths of freshwater residency of up to 199 days (Benson et al. 2007). Individuals migrate at rates of 1.18 to 2.15 km per day. Adults do not appear to spawn in successive years but, rather, at intervals of two or more year (Erickson and Webb 2007, Webb and Erickson 2007).

According to Moyle (2002, p. 110): "Spawning takes place in deep, fast water. In the Klamath River, a pool known as The Sturgeon Hole (Humboldt County) apparently is a major spawning site, because leaping and other behavior indicative of courtship and spawning are often observed there during spring and early summer." Female green sturgeon produce 51,000-224,000 eggs (Adams et al. 2002) which have an average diameter of 4.3 mm (Van Eenennaam et al. 2006). Based on their similarity to white sturgeon, green sturgeon eggs probably hatch around 196 hours (at 13°C) after spawning and the larvae should be 8-19 mm long (Gisbert and Doroshov 2006); juveniles likely range in size from 2.0 to 150 cm TL (Emmett et al. 1991). Morphological (large pectoral fins) and behavioral (rostral wedging) traits allow smaller green sturgeon to hold in rivers for extended periods of time (Allen et al. 2006). Juvenile green sturgeon appear to be largely nocturnal in their migratory, feeding and rearing behavior during the first 10 months of life (Kynard et al. 2005). Green sturgeon retinas are dominated by rods, supporting the idea that they are adapted to live in dim environments (Sillman et al. 2005).

Most juveniles migrate out to sea before two years of age, primarily during summer through fall (Emmett et al. 1991, Allen et al. 2009). Length-frequency analyses of northern green sturgeon caught in the Klamath Estuary by beach seine indicate that most green sturgeon leave the system at lengths of 30-60 cm, when they are 1 to 4 years old, although the majority apparently leave as yearlings (USFWS 1982). Although juvenile green sturgeon can withstand brackish (10 ppt) water at any age, their ability to osmoregulate in salt water develops around 1.5 years of age (Allen and Cech 2007). In the ocean, adults make annual migrations northward in the fall and southward in the spring (Lindley et al. 2008). Important overwintering habitats have been identified between Cape Spencer, Alaska and Vancouver Island. Adults can migrate more than 50 km per day during return spring migrations. Individuals from all spawning populations are known to congregate at Willapa Bay, Washington in the summer (Moser and Lindley 2007).

Northern green sturgeon grow approximately 7 cm per year until they reach maturity at 130-140 cm TL, around age 15-20 years. Thereafter, growth slows. The maximum size is presumed to be around 230 cm TL (USFWS 1982). The oldest fish known are 42 years, based on annuli of fin rays, but the largest fish are probably much older (T. Kisanuki, pers. comm., 1995). Juveniles and adults are benthic feeders on both invertebrates and fish. Adult sturgeon caught in Washington feed mainly on sand lances (*Ammodytes hexapterus*) and callianassid shrimp (P. Foley, pers. comm., 1992). In the Columbia River estuary, green sturgeon are known to feed on anchovies and, perhaps, on clams (C. Tracy, minutes to USFWS meeting). Adults may optimize growth in the summer by feeding on burrowing shrimp in the relatively warmer waters of Washington estuaries (Moser and Lindley 2007).

Habitat Requirements: The habitat requirements of northern green sturgeon are not well studied, but spawning and larval ecology are probably similar to that of white sturgeon. Preferred spawning substrate is likely large cobble, but can range from clean sand to bedrock (Nguyen and Crocker 2007). Eggs are broadcast-spawned and externally fertilized in relatively fast water at depths >3 m (Emmett et al. 1991). Excessive silt can prevent embryos from adhering to one another (Gisbert et al. 2001). Sand can impair the growth and survival of larval green sturgeon by decreasing feeding effectiveness (Nguyen and Crocker 2007).

Temperature appears to be closely linked to migration timing. In the Rogue River, adults enter freshwater from March through May, when water temperatures range from 9 to 16 °C (Erickson and Webb 2007). Adults may hold in deep (>5 m) pools with low velocities after spawning for up to six months (Erickson et al. 2002, Benson et al. 2007). Adult river outmigration initiates with low river temperatures (< 12 °C) and increases in flow (>100 cms). Juveniles appear to prefer dark, deep pools with large rock substrate during winter rearing (Kynard et al. 2005). Nocturnal downstream migration by juveniles continues until water temperatures decrease to about 8°C (Kynard et al. 2005).

Temperature has a major influence on green sturgeon physiology and survival. The upper thermal limit for developing embryos is 17- 18 °C (Van Eenennaam et al. 2005). Incubation temperatures above 22°C result in deformities (Mayfield and Cech 2004, Werner et al. 2007) and/or mortality (Van Eenennaam et al. 2005) of developing embryos. Although age 1 to 3 year old green sturgeon appear to tolerate moderate changes in water temperatures (Kaufman et al. 2007), optimal temperatures for age 1 juvenile sturgeon range from 11 to 19°C. In this same age group, temperatures between 19 and 24°C increase metabolic costs, while temperatures above 24 °C cause severe stress (Mayfield and Cech 2004). However, the metabolic costs associated with temperatures between 19 and 24 °C may be offset when food and oxygen are abundantly available, resulting in unimpaired growth (Allen et al. 2006). Kaufman et al. (2006) determined that juvenile green sturgeon are limited in their ability to handle increases in CO_2. Time of day, length of exposure to a given stressor, and temperature affect the ability of green sturgeon juveniles to respond to stress (Lankford et al. 2003, Werner et al. 2007).

Distribution: Green sturgeon have been caught in the Pacific Ocean from the Bering Sea to Ensenada, Mexico, a range which includes the entire coast of California. However, except for a few tagged fish, it is not known from which river(s), or DPS, ocean-caught sturgeon originate. Migrations generally follow northern routes along shallow waters within the 110 m contour, with individuals from all populations congregating in Willapa Bay, Washington (Moser and Lindley 2007). There are records of green sturgeon from rivers in British Columbia south to the Sacramento River. There is no evidence of green sturgeon spawning in Canada or Alaska, although small numbers have been caught in the Fraser, Nass, Stikine, Skeena and Taku rivers, British Columbia (COSEWIC 2004). Green sturgeon are common in the Columbia River estuary and were observed as far as 225 km inland in the Columbia River, prior to the construction of

Bonneville Dam (Wydoski and Whitney 1979). They apparently do not spawn in the Columbia River or other rivers in Washington, although Israel (2004) discussed genetic evidence for a distinct Columbia River population. In Oregon, juvenile green sturgeon have been found in several coastal rivers (Emmett et al. 1991) but spawning is confirmed only in the Rogue River (Erickson et al. 2002, Erickson and Webb 2007). For northern green sturgeon, spawning has been confirmed in recent years only in the Klamath and Rogue rivers (Moyle 2002, Adams et al. 2007). However, repeated observations of small numbers of adult and juvenile green sturgeon in the Eel River since 2002 suggest spawning may have resumed there after decades of spawning absence (Higgins 2013). There is some evidence of occasional spawning in the Umpqua River (Farr and Kern 2005). Overall, it is likely that northern green sturgeon once spawned in the larger coastal rivers from the Eel River in California north to the Columbia River in Oregon/Washington. Today, the Klamath River is presumed to be the principal spawning river, based on size, flow/temperature regime, and habitat availability.

The following distributional information on northern green sturgeon in California waters was compiled by Patrick Foley (University of California, Davis 1992) and updated with information in Adams et al. (2007).

North Coast. From the Eel River northward, it is likely that most records of sturgeon caught in rivers and estuaries refer to northern green sturgeon. However, most early references regarding sturgeon from the north coast did not identify the species and some reports indicated white sturgeon to be more abundant (Fry 1979). While white sturgeon do occur on occasion in the Klamath and other rivers, it is highly likely that most historic records are for northern green sturgeon. Nineteenth century newspapers (The Humboldt Times) report sturgeon from the mainstem Eel River, South Fork Eel River and Van Duzen River (Wainwright 1965). Length and weights given in these newspaper accounts are most consistent with those of adult green sturgeon.

In the 1950s, two young northern green sturgeon were collected in the mainstem Eel River and large sturgeon were observed jumping in tidewater (Murphy and DeWitt 1951). Two additional young green sturgeon (101 mm and 123 mm) were taken by CDFW from the Eel River in 1967 and are now in the fish collection at Humboldt State University. Substantial numbers of juveniles were caught by CDFW in the mainstem Eel River during trapping operations from 1967-1970 (O'Brien et al. 1976): 22 at Eel Rock in 1967, 53 at McCann in 1967 and 161 in 1969, 221 at Fort Seward in 1968, and smaller numbers at other localities. Green sturgeon have been included in lists of natural resources found in the Eel River delta (Monroe and Reynolds 1974, Blunt 1980). Adult green sturgeon are still occasionally seen in the Eel River (Adams et al. 2007). Higgins (2013) compiled seven records of green sturgeon, usually in groups, observed in the Eel River since 2002 and suggested they are now spawning in the river again. Adams et al. (2007) list the Eel River as a site of "suspected spawning."

Records of sturgeon in the Humboldt Bay system, comprising Arcata Bay to the north and Humboldt Bay to the south, are almost exclusively green sturgeon. Ten years of trawl investigations in south Humboldt Bay produced three green sturgeon (Samuelson 1973). Records from Arcata Bay are more numerous. On August 6 and 7, 1956, 50 green sturgeon were tagged in Arcata Bay by CDFW biologist Ed Best (D. Kohlhorst, pers. comm.). Total length ranged from 57.2 cm to 148.6 cm with a mean TL of 87.0 cm (± 20.6 cm SD). In 1974, nine green sturgeon were collected over a two-month period in Arcata Bay (Sopher 1974). Total length of these fish ranged between 73-112 cm TL. The Coast Oyster Company, Eureka, pulls an annual series of trawls in Arcata Bay in order to decrease the abundance of bat rays, *Myliobatis californica*. Green sturgeon are incidentally taken in this operation. Eight green sturgeon collected for parasite evaluation in 1988 and 1989 had total lengths ranging between 78-114 cm. One large individual, 178 cm TL and 18.2 kg, was returned to the bay. In 2007, green sturgeon tagged with acoustic tags were detected moving in and out of Humboldt Bay by an array set up to study the movements of coho salmon (S. Lindley, USFWS, unpublished report). Both northern and southern green sturgeon use Humboldt Bay during spring and fall (S. Lindley, pers. comm. 2009) as summarized in Tables 1-3.

Northern green sturgeon have been reported from the Mad River (Fry 1979), but evidence of their recent presence is scant (Bruce Barngrover, pers. comm. 1992). One adult was trapped in the lower river near Mad River Hatchery and rescued by CDFW biologists in 2005 (M. Gilroy, pers. comm. 2011). A carcass was also found in July, 2010 (T. Moore, file report, CDFG, 2010). California Department of Fish and Wildlife biologists D. McLeod and L. Preston observed a 1+ m long sturgeon, most likely a green sturgeon, in a gravel extraction trench in the mainstem Mad upstream of the Blue Lake Bridge (river mile 16) on May 20, 1992.

An occasional green sturgeon is encountered in the coastal lagoons of Humboldt County (Terry Roelofs, pers. comm. 1992). Big Lagoon and Stone Lagoon are connected to the ocean during part of the year and migrating sturgeon may gain entry at this time. In June, 1991, a 120-cm TL green sturgeon was gillnetted in Stone Lagoon (Terry Roelofs, pers. comm. 1992).

Green Sturgeon Tag Code	*Tagging Origin*	*First Detection*	*Last Detection*	***Number of Detections***
0111	Rogue River	July	July	20
0907	**San Pablo Bay**	**June**	**August**	**1,391**
0918	**San Pablo Bay**	**September**	**October**	**5,995**
0933	San Pablo Bay	September	September	5
0989	**San Pablo Bay**	**June**	**September**	**6,660**
1004	**San Pablo Bay**	**September**	**September**	**4**
1008	**San Pablo Bay**	**September**	**September**	**15**
1072	Rogue River	August 6	October	10,218
1127	Willapa Bay	August	August	22
1138	**Willapa Bay**	**June**	**October**	**3,401**
1187	Grays Harbor	June	July	45

Table 1. Green sturgeon detections in 2006, Humboldt Bay, California, recorded on acoustic receiver network maintained by Arcata Fish and Wildlife Office, U.S. Fish and Wildlife Service. Tag codes in bold were detected both in 2006 and 2007. (Provided by W. Pinnix, USFWS, 2012). No fish were tagged in Humboldt Bay.

Green Sturgeon Tag Code	*Tagging Origin*	*First Detection*	*Last Detection*	***Number of Detections***
0151	Sacramento River	July	August	196
0182	Sacramento River	July	August	29,327
0223	Sacramento River	May	July	15,467
0897	San Pablo Bay	July	August	624
0903	San Pablo Bay	July	July	3
0906	San Pablo Bay	July	September	1,186
0907	**San Pablo Bay**	**May**	**August**	**9,033**
0918	**San Pablo Bay**	**July**	**September**	**19,077**
0982	San Pablo Bay	July	July	83
0989	**San Pablo Bay**	**April**	**July**	**625**
0990	San Pablo Bay	July	October	15,019
0995	San Pablo Bay	September	September	39
1004	**San Pablo Bay**	**July**	**July**	**3**
1008	**San Pablo Bay**	**July**	**July**	**73**
1138	**Willapa Bay**	**May**	**September**	**16,938**
1144	Willapa Bay	July	July	344
1147	Willapa Bay	July	July	3
1173	Grays Harbor	May	May	384
1180	Grays Harbor	June	June	241
1182	Grays Harbor	June	June	275
2203	San Pablo Bay	May	August	128
2216	San Pablo Bay	August	August	17
2220	San Pablo Bay	April	July	135
2222	San Pablo Bay	July	October	5,874
2225	San Pablo Bay	September	September	15

Table 2. Green sturgeon detections in 2007, Humboldt Bay, California, recorded on acoustic receiver network maintained by Arcata Fish and Wildlife Office, U.S. Fish and Wildlife Service. Tag codes in bold were detected both in 2006 and 2007. (Provided by W. Pinnix, USFWS, 2012). No fish were tagged in Humboldt Bay.

Green Sturgeon Tag Code	*Tagging Origin*	*First Detection*	*Last Detection*	***Number of Detections***
0219	Sacramento River	June	August	793
0223	**Sacramento River**	**September**	**September**	**12,302**
0238	Sacramento River	September	September	1
0438	Sac???	September	September	3
0906	**San Pablo Bay**	**June**	**June**	**1,637**
0907	**San Pablo Bay**	**May**	**August**	**7,415**
0913	San Pablo Bay	June	September	16,705
0918	**San Pablo Bay**	**September**	**September**	**2,971**
0979	San Pablo Bay	September	September	3
0984	San Pablo Bay	July	July	24
0985	San Pablo Bay	August	August	88
0989	**San Pablo Bay**	**March**	**March**	**3**
0990	**San Pablo Bay**	**August**	**September**	**9,763**
1005	San Pablo Bay	August	August	1
1138	**Willapa Bay**	**June**	**September**	**6,827**
1144	**Willapa Bay**	**August**	**August**	**165**
1153	Willapa??	July	July	1
2203	**San Pablo Bay**	**May**	**May**	**3**
2210	San Pablo Bay	August	August	174
2212	San Pablo Bay	August	September	425
2217	San Pablo Bay	June	August	415
2225	San Pablo Bay	September	September	15

Table 3. Green sturgeon detections in 2008, Humboldt Bay, California, recorded on acoustic receiver network maintained by Arcata Fish and Wildlife Office, U.S. Fish and Wildlife Service. Tag codes in bold were detected both in 2007 and 2008. (Provided by W. Pinnix, USFWS, 2012). No fish were tagged in Humboldt Bay.

<u>Klamath and Trinity rivers</u>. The largest spawning population of northern green sturgeon in California is in the Klamath River basin. Both green sturgeon and white sturgeon have been found in the Klamath River estuary (Snyder 1908b, USFWS 1980-91), but white sturgeon are taken infrequently in very low numbers and are presumed to be coastal migrants (USFWS 1982). Almost all sturgeon found above the estuary during systematic sampling have been green sturgeon (USFWS 1980-83). Green sturgeon primarily use the mainstem Klamath River and mainstem Trinity River but have also been seen in the lower portions of the Salmon River (Adams et al. 2007).

Both adult and juvenile northern green sturgeon have been identified in the mainstem Klamath River. Adults are taken annually from spring through summer by an in-river tribal gillnet fishery. The numbers taken are between 200 and 750 fish per year (Table 5). They have also been taken by sport fishermen as far inland as Happy Camp (river km 172; unpubl. CDFW tagging data 1969-73, Fry 1979, USFWS 1981). The apparent upstream limit for spawning migration is Ishi Pishi Falls, Siskiyou County, at approximately river km 113. A few juveniles have been taken as high up as Big Bar at river km 81 (Tom Kisanuki, pers. comm. 1995) but most have been recovered by seining operations directed at salmonids in the estuary (USFWS, CDFW). Sampling by the USFWS captured 7 juveniles in 1991 and 23 in 1992 (T. Kisanuki, pers. comm. 1995). Six outmigrant traps placed in the Klamath River caught juvenile green sturgeon every year (2000-2005) (Cunanan and Hines 2006, USFWS, unpublished data). The number of green sturgeon captured each year varied from one (2005) to 775 (2003). The total number of juvenile green sturgeon captured over the six years of operation was 1599, with sizes varying from 20 mm to 252 mm TL and averaging 68.5 mm TL. Green sturgeon captured by the traps were most likely juveniles ranging in age from a couple of weeks to less than two years old, based on growth curves developed by Nakamato et al. (1995) and Van Eenennamm et al. (2001). The average size (69 mm TL) was similar to the size of artificially reared Klamath River green sturgeon at 35 days old (66 mm; Van Eenennaam et al. 2001).

The Trinity River enters the Klamath River at Weitchpec (river km 70). The first green sturgeon described from the Klamath basin came from the Trinity River (Gilbert 1897). Both adults and juveniles have been identified; 211 green sturgeon, between 7-29 cm TL, were captured in screw traps near Willow Creek, Humboldt County, incidental to a salmonid migration study in July-September, 1968 (Healey 1970). The USFWS has collected small numbers of juvenile green sturgeon from the Trinity River, as far up as Big Bar (T. Kisanuki, pers. comm. 1992). Adults are caught yearly in a tribal gillnet fishery (USFWS 1980), a traditional fishery with a long history (Kroeber and Barrett 1960). Spawning adults migrate the mainstem Trinity River up to about Grays Falls, Burnt Ranch, Trinity County (river km 72).

Northern green sturgeon have also been reported to use the South Fork Trinity River, a third-order stream entering above Willow Creek (river km 51) (USFWS 1981), according to oral histories from long-time residents. However, a large flood in 1964 had devastating effects on anadromous fish habitat in this subbasin (U.S. Department of the Interior 1985). Millions of cubic yards of soil were moved into South Fork Trinity River and its tributaries, with resulting channel widening and loss of depth in many areas. This event, along with other changes in basin morphology, has apparently resulted in the loss of suitable sturgeon habitat. There are no recent records of green sturgeon from this watershed.

The Salmon River is a fourth-order stream entering the Klamath River at Somes Bar (river km 106). Adult green sturgeon have been observed upstream as far as the mouth of Wooley Creek (river km 8).

Del Norte County. Northern green sturgeon have been taken during gillnet sampling in Lake Earl (D. McLeod, pers. comm.). Lake Earl is located along the coast of Del Norte County, 8 km north of Crescent City and 11 km south of the mouth of Smith River. Lake Earl is connected to Lake Talawa, a smaller lake directly to the west. A sand spit separates Lake Talawa from the ocean and is occasionally breached by winter storms or mechanically per the Lake Earl Wildlife Area Management Plan. Coastal migrant green sturgeon may enter at this time and become trapped after the sand spit is reestablished (Monroe et al. 1975).

The Smith River is the northernmost river along the California coast, entering the ocean approximately 5 km south of the Oregon border. Blunt (1980) included green sturgeon in an inventory of anadromous species found in the Smith River. They occasionally enter the estuary and have been observed in Patrick's Creek, an upstream tributary 53 km from the ocean (Monroe et al. 1975). Juveniles have not been found in the Smith drainage.

Trends in Abundance. Although northern green sturgeon apparently occur in fewer streams than they did historically, trends in abundance are poorly understood (Adams et al. 2002). The only time series data available for adult green sturgeon abundance in the Klamath River comes from tribal catch data (see below). The number of females spawning in the Klamath River is estimated at 760-1500 per year. The population of subadults-adults is estimated at tens of

thousands, with no clear evidence of population decline (Adams et al. 2002).
However, northern green sturgeon abundance and population trends remain largely unknown and should be treated conservatively until information indicates otherwise because:

(1) Virtually all other sturgeon species are in decline. Rochard et al. (1990) state in their review of the status of sturgeons worldwide: "Those [species of sturgeon] which do not have particular interest to fishermen (*A. medirostris, Pseudoscaphirhynchus* spp.) are paradoxically most at risk, for we know so little about them" (p. 131). The southern green sturgeon is listed as a threatened species.

(2) The only confirmed spawning populations of northern green sturgeon are in the Klamath and Rogue (Oregon) rivers, both of which have flow and temperature regimes affected by water projects and, potentially, climate change. It is highly probable that these are now the only spawning populations in North America, although recent reports from the Eel River are promising.

(3) Green sturgeon are subject to legal, illegal, and by-catch fisheries. It is likely that these fisheries depend largely on sturgeon from the Klamath River. The various fisheries, including past sport fishing, have harvested at least 6,000 to 11,000 green sturgeon per year. Studies have shown that green sturgeon populations are sensitive to overharvest (Heppell 2007).

Nature and Degree of Threats: Green sturgeon depend on large rivers so their populations are subject to numerous anthropogenic stressors that occur across large geographic areas, as described below (see Table 4).

Major dams. The Klamath, Trinity and Rogue (Oregon) rivers all have flows regulated by major dams. Apparently, the impact of these dams upon green sturgeon has been minimal perhaps because spawners tend to be in the river when flows are highest and because all life stages mainly live in the lowermost reaches, where dam impacts are reduced. However, a single green sturgeon was part of a large fish kill in the lower Klamath River in September, 2002, which has been attributed partially to the operation of Iron Gate Dam (Belchick et al. 2004), suggesting at least some vulnerability.

Grazing, roads, logging. Land use practices, such as road building, logging and grazing have all changed the quality of spawning and rearing habitats in large mainstem rivers by increasing sediment loads, impairing water quality and otherwise reducing habitat suitability. Thus, it is likely that optimal conditions (especially temperature, flow, and stream substrate composition) for spawning and rearing of green sturgeon occur less frequently now than they once (pre-1940s) did, especially during or after periods of extended drought. Of particular concern is siltation of river portions used for spawning and incubation of embryos, although the timing and location of spawning tends to reduce the probability that this is a factor in survival. The huge 1964 floods may have severely degraded many areas of sturgeon spawning and rearing habitat, perhaps eliminating this species from rivers, or tributaries thereof, such as the Eel and South Fork Trinity.

Estuary alteration. While the Klamath River estuary is relatively unmodified, other California estuaries such as those of the Eel and Smith rivers have been diked and drained for pasture or other land uses. This degradation of key rearing areas may have contributed to reductions or loss of green sturgeon and other anadromous fishes from these rivers (Yoshiyama and Moyle 2010).

Harvest. Although California anglers were prohibited from taking or possessing green sturgeon beginning in 2007, the legacy of past fishing practices may still be impacting populations today due to the species' longevity and infrequency of spawning. Of particular concern is removal of adult females from the population, which have the highest fecundity and, therefore, the greatest potential for replenishing depleted populations. The following are accounts of the two principal fisheries that may have affected green sturgeon in the northern DPS:

	Rating	Explanation
Major dams	Medium	Major dams present on all spawning rivers; however, effects are largely unknown
Agriculture	Low	Minor influence on lower Klamath and Eel rivers; alfalfa pastures for grazing widespread in the Smith estuary
Grazing	Low	Pervasive in watersheds but probably little effect on large river habitats
Rural Residential	Low	Pervasive in watersheds but probably little effect on large river habitats
Urbanization	Low	No large urban areas within known distribution
Instream mining	Low	Gravel mining and gold dredging may increase fine sediment mobilization in rivers; greater historic impact
Mining	Low	No known impact but some dredging in range (currently suspended in California)
Transportation	Medium	Roads are a source of sediment that may affect spawning
Logging	Medium	Major source of sediment from extensive network of access roads; greater historic impact
Fire	Low	Wildfires are common within the range of northern green sturgeon but impacts are not well understood
Estuary alteration	Medium	Smith and Eel estuaries are altered and have reduced capacity for rearing juvenile sturgeon
Recreation	Low	No known impact but boating may disturb fish
Harvest	Medium	Adults taken in fisheries for many years but impacts not well understood
Hatcheries	n/a	
Alien species	n/a	

Table 4. Major anthropogenic factors limiting, or potentially limiting, viability of populations of northern green sturgeon. Factors were rated on a five-level ordinal scale where a factor rated "critical" could push a species to extinction in 3 generations or 10 years, whichever is less; a factor rated "high" could push the species to extinction in 10 generations or 50 years whichever is less; a factor rated "medium" is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated "low" may reduce populations but extinction is unlikely as a result. A factor rated "n/a" has no known impact. Certainty of these judgments is moderate. See methods section for descriptions of the factors and explanation of the rating protocol.

Columbia River region. The majority of past northern green sturgeon harvest occurred in this region; they were caught by commercial fishermen, anglers, and Native American gillnetters. Sturgeon landings were recorded from the Columbia River estuary and from Grays

Harbor and Willapa Bay, Washington, to the immediate north of the estuary. There is little or no evidence of green sturgeon spawning in the rivers of this region, so it is likely that sturgeon harvested there migrated from California or Oregon, as indicated by limited recaptures of tagged individuals (Adams et al. 2007). Further evidence of the lack of local recruitment into the fishery is indicated by the fact that few juvenile sturgeon (<1.3 m) have been caught in this region (Emmett et al. 1991).

The commercial catch in the Columbia River region (Columbia River estuary, Grays Harbor, Willapa Bay) has fluctuated considerably over time, but catches appear to have increased in recent decades. Between 1941 and 1951, catches averaged about 200-500 fish per year, while between 1951 and 1971 the catch averaged about 1,400 fish per year (Houston 1988). In the late 1980s, an average of 4.7 tons of green sturgeon (ca. 500-1,000 fish) were harvested each year in Grays Harbor and 15.9 tons (ca. 2,000-4,000 fish) were harvested in Willapa Bay (Emmett et al. 1991). There have also been some notably high catches; in 1986, 6,000 green sturgeon were harvested in the Columbia River estuary (Oregon Dept. of Fish and Wildlife (ODFW) 1991) and 4,900 were taken in 1987 (ODFW, unpubl. data). From the 1960s-1980s, the commercial catch of green sturgeon in the Columbia River has averaged 1,440 fish (1960s), 1,610 (1970s) and 2,360 (1980s); the catch since 1990 has ranged from 3200 fish (1991) to 0 fish (2002) (Adams 2007). The Columbia River recreational catch has been consistently below 200 fish per year since 1988 (ODFW 1991, Adams 2007). For 1985-2003, Adams et al. (2007) estimated annual harvest of green sturgeon from all sources as ranging from 500 to over 9000 fish, with catches since 2001 being less than 1,000 fish per year, mostly taken in Washington. While fishing for green sturgeon is now prohibited in Washington, some mortality from fishing presumably continues as the result of by-catch from other fisheries (Adams et al. 2002). The commercial fishery took both northern and southern green sturgeon; only tagged fish were identified to the appropriate DPS.

<u>Klamath and Trinity rivers</u>. A small number of northern green sturgeon were probably taken in this sport fishery in the past but the main harvest is now by the Yurok, Karuk, and Hupa tribal gillnet fisheries (USFWS 1990, Adams et al. 2005). A small, but possibly significant, number are also taken in an illegal snag fishery. All fisheries target sturgeon as they move upriver to spawn during the spring and as they return seaward through the estuary during June-August (USFWS 1990). In the tribal fishery, mainly adult sturgeon (>130 cm FL) are captured (mean length 179 cm FL in 1988). The percent of the total (sport and tribal) harvest in the Pacific Northwest taken from the Klamath River increased from a low of 5% in 1987 to 59% in 2003 (Van Eenennaam et al. 2006, Table 5). This increase most likely reflected changes in regulations to limit green sturgeon harvest in Oregon and Washington (Adams et al. 2002).

	Klamath River				Total Harvest (CA, OR, WA)	Percent of Total Harvest from Klamath River
Year	Yurok	Hupa	Sport	Total		
1985	351	10	NA	361	5,156	7
1986	421	30	153	604	9,065	7
1987	171	20	170	361	7,669	5
1988	212	20	258	490	6,514	8
1989	268	30	202	500	4,067	12
1990	242	20	157	419	4,736	9
1991	312	13	366	691	6,788	10
1992	212	3	197	412	4,551	9
1993	417	10	293	720	4,267	17
1994	293	14	160	467	1,342	35
1995	131	2	78	211	1,286	16
1996	119	17	210	346	1,692	20
1997	306	7	158	471	3,199	15
1998	335	10	103	448	1,692	26
1999	204	27	73	304	1,491	20
2000	162	31	15	208	1,796	12
2001	268	10	NA	278	862	32
2002	273	5	NA	278	696	40
2003	287	16	NA	303	514	59
2004	222	12	NA	234	NA	NA

Table 5. Green sturgeon harvest numbers and percent of total harvest (California, Oregon and Washington combined) from the Klamath River, California (Source: Adams et al. 2002, Van Eenennaam et al. 2006).

The average total length of northern green sturgeon captured in the Yurok Tribal fishery increased slightly from 1980 to 2004 (Figure 1). Moreover, the proportion of green sturgeon greater than 190 cm increased from 30% in 1995 to approximately 40% in 2004 (D. Hillemeier, Yurok Tribal Fisheries Program, unpublished data). Because the length of captured individuals did not decrease, the Yurok Tribal fishery apparently does not adversely impact the size distribution of spawning adults. However, it is uncertain whether the increase in numbers of large adults signifies a change in population structure towards larger individuals or a loss of younger year classes.

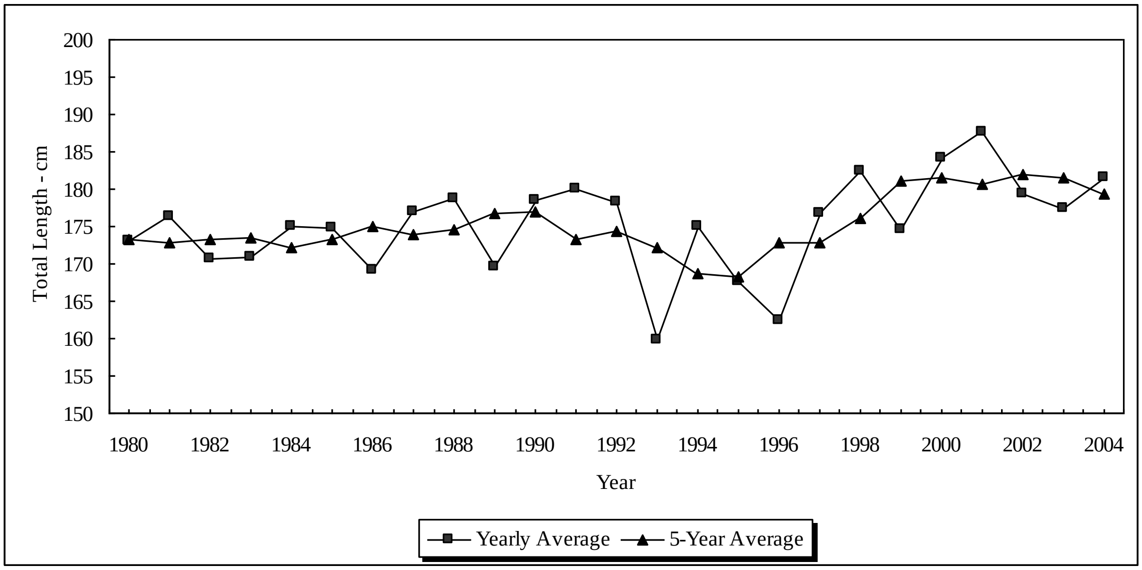

Figure 1. Average total length of northern green sturgeon sampled in the Yurok fishery, 1980-2004 (Source: D. Hillemeier, Yurok Tribal Fisheries Program, unpublished data).

Although present in low numbers, there is no indication that green sturgeon are in decline in the Klamath River basin (Adams et al. 2002, 2005; Beamesderfer and Webb 2002). However, given the status of other anadromous species in the Klamath River basin, the extended freshwater residency of at least some individuals, delayed maturity, and longevity of green sturgeon, there is concern that adverse impacts to the population may not be detected unless they are analyzed at the appropriate time scale (17 to 23 years; D. Hillemeier, unpublished data).

Effects of Climate Change: Increased water temperatures brought about by climate change may place northern green sturgeon under chronic stress that can result in metabolic costs that impair reproduction, growth and immune function (Lankford et al. 2005). Mayfield and Cech (2004) recommended that, in order to enhance growth, management plans should protect green sturgeon from prolonged exposure to temperatures above 19°C. Similarly, Van Eenennaam et al. (2005) concluded that temperatures above 20°C are detrimental to reproduction and most likely result in low hatching success, especially during dry water years. Summer water temperatures in the mainstem Klamath River already frequently exceed 20°C and temperatures in California are expected to increase under all climate change scenarios (Hayhoe et al. 2004, Cayan et al. 2008). Increases in summer temperatures may affect the growth and metabolic costs of juvenile and adult green sturgeon that hold in rivers throughout the summer. Climate change is also predicted to alter the flow regimes in rivers. In the Klamath and Trinity rivers, river flow may peak earlier in the spring and continue tapering through the summer before pulsing again later in the fall. The resulting changes in river flow and temperature may change the timing of adults and juveniles entering and exiting these systems. Quiñones and Moyle (2012) predicted these changes will cause increased declines in anadromous salmonids in the Klamath basin, so negative impacts to green sturgeon are likely as well. Moyle et al. (2013) rated northern green sturgeon as "highly vulnerable" to extinction in California as the result of climate change, largely as a result of increased temperatures and reduced flows in the Klamath River.

Status Determination Score = 2.7 - High Concern (see Methods section, Table 2)**.** Northern green sturgeon merit high concern status, even though they are not in immediate danger of extirpation from California. The Klamath-Trinity River population is the sole reproducing population in California and, apparently, is by far the largest population, giving it added significance. Green sturgeon are considered to be a threatened species in Canada. In 2006, the National Marine Fisheries Service determined that the northern green sturgeon DPS did not warrant listing under the Federal Endangered Species Act (50 CFR part 223); however, it was designated a species of concern (www.nmfs.noaa.gov). Green sturgeon (both DPS's combined) are given a near-threatened status by International Union for Conservation of Nature (IUCN) Red List (www.iucnredlist.org). The southern (Sacramento) DPS of green sturgeon was listed in 2006 as a threatened species under the Federal Endangered Species Act. After the southern green sturgeon was listed, both Oregon and Washington banned take by both commercial and sport fisheries.

Metric	Score	Justification
Area occupied	1	Only Klamath-Trinity population appears to be self-sustaining in California - this would score '2' if Oregon populations were included
Estimated adult abundance	2	Unknown, but 1,000-5,000 adults would be a conservative estimate
Intervention dependence	4	Long-term persistence depends on fisheries management and habitat restoration
Tolerance	3	Fairly tolerant of conditions in the Klamath River although susceptible to warm temperatures
Genetic risk	4	Presumably some genetic connections to Rogue population
Climate change	2	Limited spawning and rearing habitats suggests vulnerability to increased temperatures, reduced summers flows and other climate change-related stressors
Anthropogenic threats	3	Five threats scored 'medium' (see Table 4)
Average	2.7	19/7
Certainty	3	Abundance not well understood but many publications exist on distribution and behavior

Table 6. Metrics for determining the status of northern green sturgeon, where 1 is a major negative factor contributing to status, 5 is a factor with no or positive effects on status, and 2-4 are intermediate values. See methods section for further explanation.

In California, only one spawning population is recognized in the Klamath River, raising concerns about limited genetic diversity and gene flow. The possibly reproducing population in the Eel River is presumably derived from strays from the Klamath River. Conditions in the Klamath River for spawning and rearing have likely worsened due to the presence of major dams in both the main stem Klamath and Trinity rivers. Dams have dramatically altered the hydrology and geomorphology of these systems (NRC 2004). Degradation of habitats, combined with the predicted effects of climate change, make northern green sturgeon vulnerable to changing environmental conditions and potentially less suitable habitat conditions.

The closure of green sturgeon fishing, except for tribal fisheries, has reduced harvest rates in California. However, the legacy of harvest prior to 2007 may still be impairing the recovery of some populations. Green sturgeon population growth is particularly sensitive to adult and subadult mortality, especially if the effective spawning population size becomes low (Heppell 2007). Large increases in egg production and juvenile survival are required to counterbalance the impact from even relatively low levels of fishing mortality. In addition, recent work (Israel et al. 2004) suggests that not all spawning populations of green sturgeon have been identified, a necessary step for the adequate protection of green sturgeon genetic diversity.

Management Recommendations: The following conservation measures are needed to maintain or increase northern green sturgeon abundances:

1. Detailed studies on life history and ecological requirements are needed. Current population assessment and monitoring by the USFWS, Yurok Tribe, and others should be expanded, particularly for Klamath River populations. The current paucity of information and empirical data about the population status, structure and dynamics of northern green sturgeon means that population trends cannot be predicted, nor stocks properly managed. Females mature relatively late in life and may not spawn every year, so maintenance of sufficient reproductive potential (i.e., numbers of mature females) in populations is an important management consideration.

2. Nursery habitats for juveniles in river and estuarine habitats need to be identified and protected. One method for determining optimal habitats is to examine the digestive tracts of juvenile green sturgeon to evaluate the nutritional condition of fish rearing in different habitats (Gisbert and Doroshov 2003). Shortages of food supply can disrupt the organization and generation of juvenile digestive systems, directly affecting growth and survival.

3. Tribal fisheries that target northern green sturgeon should be limited until more is known about the biology and abundance of this species. At a minimum, special harvest regulations for green sturgeon are needed to reduce the catch of large females of peak reproductive ages of 25 to 40 years old (Heppell 2007). The effect of harvest on population productivity could be reduced by a slot limit to reduce the number of age classes harvested (Heppell 2007).

4. Populations can benefit from habitat restoration, especially of estuaries and lagoons. Measures should be adopted to keep summer water temperatures below 20°C, where possible, and to decrease the input of fine sediments into streams. Both of these measures can enhance the development and subsequent recruitment of juvenile green sturgeon.

5. The effects on northern green sturgeon of the proposed removal of four dams on the Klamath River need to be evaluated, especially in relation to low summer flows (e.g., lack of year-round tailwater flows from controlled dam releases) and with respect to potential for green sturgeon to use habitats made available by dam removal.

Figure 2. Freshwater distribution of northern green sturgeon, *Acipenser medirostris* (Ayres), in California. The only confirmed spawning population is in the Klamath-Trinity river system.