Population Status of North American Green Sturgeon, Acipenser medirostris

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Abstract North American green sturgeon, *Acipenser medirostris*, was petitioned for listing under the Endangered Species Act (ESA). The two questions that need to be answered when considering an ESA listing are; (1) Is the entity a species under the ESA and if so (2) is the "species" in danger of extinction or likely to become an endangered species in the foreseeable future throughout all or a significant portion of its range? Green sturgeon genetic analyses showed strong differentiation between northern and southern populations, and therefore, the species was divided into Northern and Southern Distinct Population Segments (DPSs). The Northern DPS includes populations in the Rogue, Klamath-Trinity, and Eel rivers, while the Southern DPS only includes a single population in the Sacramento River. The principal risk factors for green sturgeon include loss of spawning habitat, harvest, and entrainment. The Northern DPS is not considered to be in danger of extinction or likely to become an endangered species in the foreseeable future. The loss of spawning habitat is not large enough to threaten this DPS, although the Eel River has been severely impacted by sedimentation due to poor land use practices and floods. The two main spawning populations in the Rogue and Klamath-Trinity rivers occupy separate basins reducing the potential for loss of the DPS through catastrophic events. Harvest has been substantially reduced and green sturgeon in this DPS do not face substantial entrainment loss. However there are significant concerns due to lack of information, flow and temperature issues, and habitat degradation. The Southern DPS is considered likely to become an endangered species in the foreseeable future. Green sturgeon in this DPS are concentrated into one spawning area outside of their natural habitat in the Sacramento River, making them vulnerable to catastrophic extinction. Green sturgeon spawning areas have been lost from the area above Shasta Dam on the Sacramento River and Oroville Dam on the Feather River. Entrainment of individuals into water diversion projects is an additional source of risk, and the large decline in numbers of green sturgeon entrained since 1986 causes additional concern.

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Introduction

The North American green sturgeon, *Acipenser medirostris*, have been petitioned for listing under the Endangered Species Act (ESA) and this is a review of the scientific considerations that the National Marine Fisheries Service uses to consider listing. Sturgeons in general have a life history that is susceptible to overharvesting and degradation of freshwater habitat and a number of species have some kind of protection or conservation status (Secor et al. 2002). In the United States, there are five ESA listed sturgeon: shortnose sturgeon, *A. brevirostrum*, Endangered (USFWS 1967); Pallid sturgeon, *Scaphirhynchus albus*, Endangered (USFWS 1990); Gulf sturgeon, *A. oxyrinchus desotoi*, Threatened (USFWS and NOAA 1991); white sturgeon, Kootenai River Population, *A. transmontanus*, Endangered (USFWS 1994); and Alabama sturgeon, *S. suttkusi*, Endangered (USFWS 2000). Green sturgeon has a status designation of Special Concern in Canada (Houston 1988) because of its population characteristics that make it particularly sensitive to human activities or natural catastrophic events. Sakhalin sturgeon, *A. mikadoi*, a species that was at one time synonymized with green sturgeon, is extirpated throughout Japan, Korea, and China. In Russia, Sakhalin sturgeon now only occurs in the Tumnin River where there is a hatchery supporting it.

There are two key questions that must be addressed in determining whether a listing under the ESA is warranted: (1) Is the entity in question a "species" as defined by the ESA, and (2) if so, is the "species" in danger of extinction or likely to become an endangered species in the foreseeable future throughout all or a significant portion of its range? For the purpose of the ESA, a species is defined as "any subspecies of fish or wildlife or plants, or any distinct population segment (DPS) of any species of vertebrate fish or wildlife which interbreeds when mature." The ESA allows listing of "distinct population segments" of vertebrates as well as named species and subspecies. Two elements are necessary for a decision to identify separate DPSs (UFSWS and NOAA 1996): discreteness and significance of the population segment to the species. A DPS may be considered discrete if it is markedly separate from other populations of the same taxon as a consequence of physical, physiological, ecological, or behavioral factors or if it is delimited by international governmental boundaries. If a population segment is considered discrete, it's biological and ecological significance will be considered on the basis of considerations including, but not limited to its persistence, evidence that loss of the DPS would result in a significant gap in spatial structure, evidence of the DPS representing the only surviving natural occurrence of a taxon, or evidence that the DPS differs markedly in its genetic characteristics.

The ESA defines the term "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." The term "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." In evaluating the level of risk faced by a species or DPS, important considerations include (1) absolute numbers and their spatial and temporal distribution; (2) current abundance in relation to historical abundance and carrying capacity of the habitat; (3) any spatial and temporal trends in abundance; (4) natural and human-influenced factors that cause variability in survival and abundance; (5) possible threats to genetic integrity (e.g., artificial rearing); and (6) recent events (e.g., a drought or a change in management) that have predictable short-term consequences for abundance of the species. Additional risk factors, such as disease prevalence or changes in life history traits, may also be considered in evaluating risk to populations. The determination of whether a species as "in danger of extinction" or "likely to become an endangered species within the foreseeable future" should be made on the basis of "the best scientific and commercial information" available regarding its current status. The use of "best scientific and commercial information" is a standard makes the risk assessment process fundamentally different than typical scientific investigation. This standard requires the gathering of all information possible, including some that would not meet traditional scientific guidelines, and requires making recommendations based on imperfect and incomplete information.

Green sturgeon life history

Green sturgeon is the most widely distributed member of the sturgeon family Acipenseridae. Like all sturgeons, they are anadromous, but are also the most marine oriented of the sturgeons. The only known green sturgeon spawning locations are in Oregon and California rivers where they experience anthropogenic impacts similar to other anadromous fishes (Moyle 2002). Adults migrate into their spawning rivers, peaking in May–June, and then hold in deep pools or ''holes'' in the mainstem of large turbulent rivers to stage for spawning (Erickson et al. 2002). Eggs are likely broadcast spawned over large cobble substrate where they settle into the spaces between the cobbles. Fecundity is lower than other sturgeons, but the egg size is larger (Deng 2000). The large egg size provides more yolk stores for the nourishment of embryos, presumably resulting in more viable larvae. The adhesiveness of green sturgeon eggs is lower than that of white sturgeon and the eggs may not attach to the substrate after fertilization like white sturgeon, but become trapped in crevices and gravel during embryo development. The juveniles spend from 1–4 years in freshwater, before migrating to the ocean. Once in the ocean, green sturgeon range in coastal waters from Mexico to the Bering Sea (Moyle 2002). Tagging has shown that they make long migrations in the ocean, generally to the north[1] and analyses of Oregon trawl catch found them almost exclusively inside the 110-m contour (Erickson and Hightower in press). Recent hydro-acoustic tagging information has shown that green sturgeon congregate near the Brooks Peninsula, and immediately north of Vancouver Island.[2] Green sturgeon congregate in coastal bays and estuaries in late summer and early fall, with particularly large concentrations in the Columbia River Estuary, Willapa Bay, and Grays Harbor.[3] The reasons for these concentrations are unclear. Green sturgeon have delayed sexual maturity, somewhere between 13 and 20 years, and they apparently only spawn every 2–5 years (Moyle 2002).

What is the ''species'' unit for ESA listing?

Review of ''species'' data

Green sturgeon that occur within United States and Canadian waters are now known to be a geographically isolated and genetically distinct species. The species was first described as *Acipenser medirostris* by Ayres (1854) from San Francisco Bay. The North American form was considered conspecific with a previously described Asian species Sakhalin sturgeon, *A. mikadoi*, and the two forms were synonymized (Berg 1948). More recent molecular data on three mitochondrial genes show large differences between the North American and Asian forms (Birstein and DeSalle 1998), and these two forms are now considered separate species. Morphometric data shows differences between the two forms with the snout of the Asian form being longer (North et al. 2002). Other morphometric and meristic data between the two forms are similar. Both Green and Sakhalin sturgeon occur in coastal waters and in estuaries. The only currently documented Sakhalin sturgeon spawning population occurs in the Tumnin River, Russia, which also has a hatchery for this species.

Sturgeons are known to have strong homing capabilities and this leads to high spawning site fidelity (Bemis and Kynard 1997). It is common to

[1] Adams, P.B., C.B. Grimes, J.E. Hightower, S.T. Lindley, and M.L. Moser. 2002. Status Review for the North American green sturgeon. Final Report to Southwest Region, NOAA Fisheries. Long Beach, CA. 50 p.

[2] S. Lindley and M. Moser. 11/22/2004. NOAA Fisheries, Santa Cruz, CA.

[3] Moyle P., P. J. Foley, and R. M. Yoshiyama. 1992. Status of green sturgeon, *Acipenser medirostris*, in California. Final Report submitted to National Marine Fisheries Service. 11 p. University of California Davis.

have a large numbers of genetically separated races or morphs within a species (Wirgin et al. 1997). The trend of sturgeon homing to individual rivers is so strong that river by river analysis is common in sturgeon ESA recovery plans. This general pattern in sturgeon population genetics led to consideration that green sturgeon might have multiple DPSs.

The actual historical and current geographical extent of green sturgeon spawning is difficult to assess because green sturgeon make non-spawning movements into coastal lagoons and bays in the late summer to fall, and because their original spawning distribution may have been reduced due to harvest and other anthropogenic effects. Green sturgeon commonly occur in coastal waters from San Francisco Bay to Canada,[1] but actual spawning has only been documented (by the presence of juveniles) in the Rogue (Erickson et al. 2002), Klamath (Scheiff et al. 2001), Trinity (Scheiff et al. 2001), Sacramento,[4] and Eel[5] rivers. The historical status of the Umpqua, Feather, and San Joaquin rivers as green sturgeon spawning areas remains unknown.

In late summer and early fall, green sturgeon commonly occur in estuaries where there has been no known spawning. The exact reason for this behavior is not known, but it greatly complicates identification of natal rivers and designation of DPSs. Green sturgeon have occurred in many estuaries where there are no records of their occurrence further up the river system. Therefore, we used the presence of juveniles to confirm green sturgeon spawning in a given river system.

Historic green sturgeon spawning distribution may never be known due to sturgeon's vulnerability to overharvest and other anthropogenic impacts (Boreman 1997, also see extinction risk section). Smaller less productive populations may have extirpated by harvest and habitat degradation long before there was any scientific recognition of their existence.

Green sturgeon population genetic analyses have recently become available (Israel et al. 2004, also[6]), but these analyses are limited by small sample size and mixed samples of different spawning populations in different years. Genetic samples were analyzed from the Klamath River, from San Pablo Bay, juveniles from the Sacramento River, from the Rogue River, from the Columbia River estuary, and from the Umpqua River estuary. Nine microsatellite loci were amplified for analysis of allele frequencies; six of these loci were tetrasomic and therefore do not permit standard genetic analysis. The genetic analyses of existing samples are problematic in those samples from estuaries since these fish may be a mixture of different spawning stocks. Ideally, coast-wide genetic studies should be conducted on juveniles collected in their natal rivers.

The results of the genetic analyses showed strong separation between a northern and southern group of spawning fish (Israel et al. 2004, this volume). The northern group contains spawning populations in the Klamath and Rogue rivers that have similar genetic composition. Non-spawning green sturgeon sampled in Umpqua Bay are also grouped with the northern group because of similar genetic composition. The southern group, which contains the Sacramento River juveniles samples and fish from San Pablo Bay, has a distinctly different genetic composition from the northern group.

The genetic data showed a complex relationship between Columbia River green sturgeon samples and samples from San Pablo Bay and the Sacramento River. There was no significant genotypic differentiation detected between San Pablo Bay and Columbia River collections. However, the San Pablo Bay samples were not identical to the Sacramento River samples from juveniles. There are a number of possible explanations for these results. One is that Columbia River fish generally come from the Sacramento River. Another is that both Columbia River and

[4] California Department of Fish and Game (CDFG). 2002. California Department of Fish and Game Comments to NMFS Regarding Green Sturgeon Listing. Sacramento, CA, 129 pp.

[5] Puckett, L. K. 1976. Observations on the downstream migrations of anadromous fishes within the Eel River system. California Department of Fish and Game. Memorandum Report. 35 p. California Department of Fish and Game, Eureka, CA.

[6] J. Israel and B. May. 2005. Univ. of California, Dept. of Animal Science, Davis, CA.

San Pablo Bay are a mixture of other spawning populations. Finally, it is possible that by chance, the small number of Columbia River samples come largely from fish that were spawned in the Sacramento River.

Conclusions and discussion on the ''species'' question

North American green sturgeon are clearly a species under the ESA. The North American species, *A. medirostris*, is a separate species from the western Pacific Tumnin River population, *A. mikadoi*, due to the lower chromosome number (Birstein et al. 1993) and morphological differences (North et al. 2002).

Current evidence justifies the separation of green sturgeon into Northern and Southern DPSs. Sturgeons generally show fidelity to their spawning sites so they have a general pattern of multiple DPSs (Bemis and Kynard 1997). The Northern DPS includes populations from the Rogue, Klamath-Trinity, and Eel rivers, and the Southern DPS currently includes only the Sacramento River population (Fig. 1). The Eel River, for which there is no genetic information, is assigned to the Northern DPS on an ''isolation by distance'' argument since the mouth of the Eel River is much closer to the Northern DPS. The ESA ''discreteness'' test that populations are markedly separated from each other is clearly met by the genetic data discussed earlier. The ESA ''significance'' test is also clearly met by genetic evidence, distribution, and adaptation to different habitats. The Northern and Southern DPSs represent the northern and southern extent of the green sturgeon's range. The loss of either of these DPSs would result in a significant shrinkage of the species distribution and would be considered the loss of a portion of the species' range. The two DPSs are also significantly separate because spawning occurs in very different habitats. The Northern DPS spawning occurs in the more coastal Klamath Mountain Province, a cooler, wetter area that supports a number of uniquely adapted salmonids (Busby et al. 1996). The Southern DPS spawning occurs in the dry, hot California Central Valley that has experienced large anthropogenic change (Lindley et al. 2006). The loss of ability to spawn in either of these different habitats would be a major loss of adaptation. There may be green sturgeon spawning locations and population structure that are not apparent now and which may cause this assessment of DPS structure to change in the future.

What is the level of ''extinction risk''?

Review of ''extinction risk'' data

Loss of spawning habitat

The amount of lost green sturgeon spawning habitat is unclear. Although there have been claims that as many as twice the number of green sturgeon spawning populations have been extirpated as currently remain,[7] these claims are impossible to evaluate because it is unknown how many spawning populations there were and if spawning populations are actually extirpated. In the Northern DPS, there is no evidence of green sturgeon spawning north of the Umpqua River, Oregon. Spawning does appear to occur in the Umpqua River, but probably is rare. There are two confirmed records of green sturgeon captured above tidal influence in the Umpqua River,[8] approximately 150 km up river. However, Oregon Department of Fish and Wildlife sampled the Umpqua River in 2002, 2003, and 2004 using gill nets, beach seines, snorkeling, and underwater video and did not collect any green sturgeon above tidal influence. Green sturgeon in the South Fork of the Trinity River were reportedly extirpated by the 1964 flood (Moyle 2002), but juvenile green sturgeon are captured at Willow Creek on the Trinity River (Scheiff et al. 2001). These fish could be coming from either the South Fork or the Trinity River. Green sturgeon still appear to occasionally occupy the Eel River.

[7] Environmental Protection Information Center (EPIC), Center for Biological Diversity, and Waterkeepers Northern California. 2001. Petition to list the North American green sturgeon (*Acipenser medirostris*) as an endangered or threatened species under the ESA. National Marine Fisheries Service. Long Beach, CA. 63 pp.

[8] T. Rien. 11/16/2004. ODFW, Clackamas, OR.

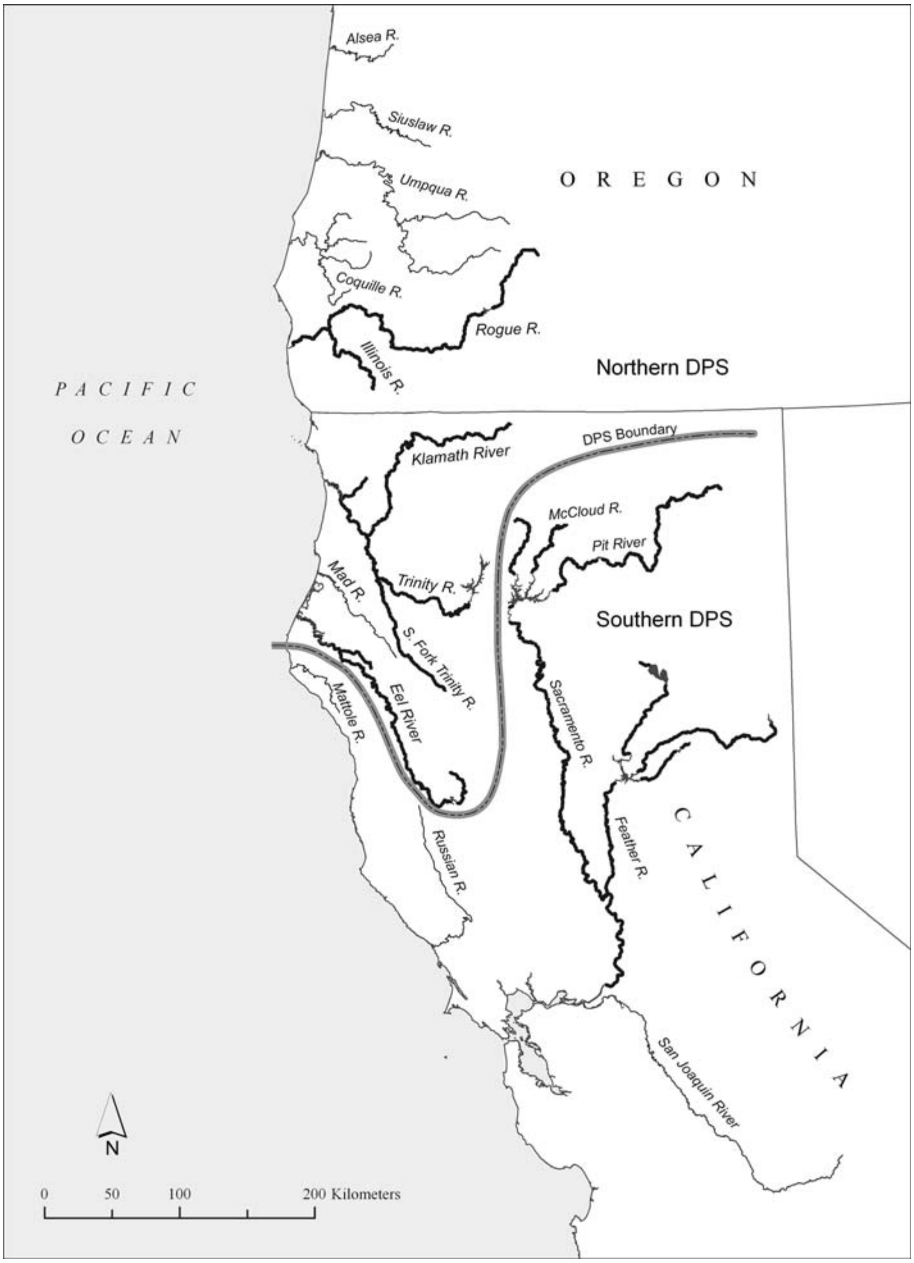

Fig. 1 Green Sturgeon DPSs. The Northern DPS includes populations from the Rogue, Klamth-Trinty, and Eel rivers. The Southern DPS includes a single population in the Sacramento River

Adult green sturgeon were sighted on the mainstem Eel River near Fort Seward (rkm 101) during snorkel surveys in 1995 and 1996.[9] Two juvenile green sturgeon (282 m and 510 mm FL) were captured in the Eel River Estuary in 1994 by trawl.[10] This is in addition to the previously reported capture of 26 juvenile green sturgeon near Fort Seward in 1967 and 1968.[5]

[9] S. Downie 10/8/2004. CDFG, Fortuna, CA.

[10] S. Cannata. 11/5/2004. CDFG, Fortuna, CA.

In the Southern DPS, recent habitat evaluations conducted in the upper Sacramento River for salmonid recovery planning suggests that significant potential green sturgeon spawning habitat was made inaccessible or altered by dams (historical habitat characteristics, temperature, and geology summarized in Lindley et al. (2004, 2006). This spawning habitat may have extended up into the three major branches of the Sacramento River; the Little Sacramento River, the Pitt River system, and the McCloud River. Green and white sturgeon adults have been observed periodically in small numbers in the Feather River[11] There are no records of larval or juvenile sturgeon of either species, even prior to the 1960's when Oroville Dam was built.[12] There are reports that green sturgeon may reproduce in the Feather River during high flow years, but these are not specific and are unconfirmed.[4] California Department of Fish and Game regards the Feather River to be ''the most likely loss of spawning habitat [of green sturgeon in the Central Valley]''.[4] They suggests that Oroville Dam blocks access to potential spawning habitat and that Thermalito Afterbay warm water releases may increase temperatures to levels that are undesirable for green sturgeon spawning and incubation. No green sturgeon has ever been documented in the San Joaquin River or its tributaries.[4, 11] Small numbers of adult sturgeon occur in the San Joaquin River, but all those identified to date have been white sturgeon. Two juvenile white sturgeon caught at Woodbridge on the Mokelumne River (rkm 63) in 2003 are the first confirmation of sturgeon reproduction in the San Joaquin River system.[11] The San Joaquin River and its tributaries have been heavily modified in ways that reduce suitability for sturgeon since the 1940's, so the lack of contemporary information cannot be considered evidence of historical green sturgeon absence.

Harvest

Green sturgeon harvest is now almost entirely bycatch in three fisheries: white sturgeon commercial and sport fisheries, Klamath Tribal salmon gill-net fisheries, and coastal groundfish trawl fisheries (Table 1). Historically, the larger take was bycatch from white sturgeon commercial and sport fisheries. Large commercial fisheries developed in the late 1800's for previously unexploited white sturgeon, and these fisheries collapsed because fishing mortality far exceeded sustainability (Galbreath 1985). The excessive white sturgeon fishing mortality likely caused an accompanying decline in green sturgeon, but the degree of green sturgeon decline is unknown. Green sturgeon do have longer ocean residence than white sturgeon and therefore may be less available to fisheries. A smaller part of the harvest occurs directly on spawning fish as bycatch to the Klamath River Yurok and Hoopa tribal gill-net salmon fishery. The tribal salmonid fishery is used for subsistence.

The total average annual harvest of green sturgeon declined substantially from 6494 fish in 1985–1989 to 1072 fish in 2000–2003 (Table 1) and has continued to decline to 512 in 2003. Historically, harvest came predominately from the Columbia River (51%), coastal trawl fisheries (28%), the Oregon fishery (8%), and the California Tribal fishery (8%). Much of the harvest reduction in recent years is due to increasingly restrictive Columbia River fishing regulations. Coastal trawl fisheries have declined to low levels since 1999 (Rein 2002). In 2003, Klamath and Columbia River Tribal fisheries accounted for 65% of the total catch.

The California Klamath Tribal fishery has historically accounted for approximately 8% of green sturgeon harvest (Table 1). This fishery is especially important because the Klamath fishery operates directly on what is thought to be the largest green sturgeon spawning population. Harvest averaged 279 fish annually with no apparent trend from 1985 to 2003. There was one extremely high catch in 1981 of 810 fish. Green

[11] Beamesderfer, R.C.P., Simpson, G. Kopp, J. Inman, A. Fuller, and D. Demko. 2004. Historical and current information on green sturgeon occurrence in the Sacramento and San Joaquin rivers and tributaries. S.P. Cramer & Associates, Inc. Gresham, OR. 46 p.

[12] A. Seesholtz. 2005. California Department of Water Resources. Sacramento, CA.

Table 1 Harvest of green sturgeon (numbers) from California, Oregon, and Washington from 1985 to 2003

Year	California			Oregon[13]		Washington[14]										
	Klamath[15]					Columbia River[16]		Willapa Bay			Greys Harbor					
	SF Bay[1]	Yurok	Hoopa	Sport	Trawl	Sport	Comm.	Comm.	Sport	Treaty[17]	Comm.	Sport	Treaty[18]	Trawl	Other[18]	Total
1985	Few	351	10		726	533	1600	1289			227		5	348	67	5156
1986	Few	421	30	153	190	407	6000	925		1	626		3	142	167	9065
1987	Few	171	20	170	124	228	4900	877			770		8	52	349	7669
1988	Few	212	20	258	120	141	3300	1598	4		609	4	1	34	213	6514
1989	Few	268	30	202	210	84	1700	461	4		870	12	2	133	91	4067
1990	Few	242	20	157	143	86	2200	953	2		734	4	9	66	120	4736
1991	Few	312	11	366	242	22	3190	957	0		1527	0	3	99	59	6788
1992	Few	212	3	197	94	73	2160	1002	0		737	0	3	66	4	4551
1993	Few	417	36	293	250	15	2220	290	32		542	112	3	37	20	4267
1994	Few	293	6	160	154	132	240	268	13	6	17	25	22	5	1	1342
1995	Few	131	6	78	29	21	390	78	8		374	96	7	3	65	1286
1996	Few	119	8	210	182	63	610	129	24		137	70	132	1	7	1692
1997	Few	306	16	158	400	41	1614	16	4		316	105	198	6	19	3199
1998	Few	335	10	103	77	73	894	65	12	2	25	28	55	0		1692
1999	Few	204	28	73	21	93	967	9	5		0	29	58	4		1491
2000	Few	162	31	15	12	32	1224	224	5		0	38	50	3		1796
2001	Few	268	10	NA	17	50	342	106	9		0	27	32	1		862
2002	Few	273	5	NA	14	51	163	0	48		7	0	131	4		696
2003	Few	287	16	NA	17	52	46	43	NA		2	NA	46	5		514

See footnotes for data sources

sturgeon catch is incidental to the chinook gill-net fishery by the Yurok and Hoopa Tribes on the lower portions of the Klamath and Trinity rivers. The green sturgeon catch is monitored but there is no direct regulation of the fishery for green sturgeon. In 2004, the tribal fisheries adopted additional conservation measures that will change the character of the catch time series.

California sport catch of green sturgeon, primarily in San Pablo Bay, is not monitored, but is thought to be only a few fish each year.[4] Until very recently, there has been no differentiation between green and white sturgeon in the regulations and the current slot limits are 117 cm to 183 cm (46 to 72 in.). In 2006, California announced an emergency closure of recreational fishing for green sturgeon.

Harvest data provide limited information about population status. Average length of Columbia River commercially caught green sturgeon has been increasing since 1990 (Rien et al. 2001), and the largest average sizes have been in recent years. In the California Klamath Tribal fishery, the percentage of green sturgeon over 175 cm TL remained unchanged from 1984 to 2001. Larger fish are increasing in proportion to the total catch in recent years.

[13] Farr et al. (2002), T. Rien., ODFW, 11/16/2004. Clackamas, OR.

[14] Washington Department of Fish and Wildlife (WDFW). 2002. Letter to Ms. Donna Darm. 5 pp. (plus enclosures, 28 p.). WDFW. 2002. Letter to Dr. Peter Adams. 5 pp.

[15] USFWS (1994) Klamath River fisheries investigation program, Annual Report—1992. Acrata, CA. 63 pp; Hillemeier, D. 2004. Yurok Tribe green sturgeon unpublished catch data. Yurok Tribe. Orcutt, CA.; Kautsky, G. 2004. Hoopa Tribe green sturgeon unpublished catch data. Hoopa, CA. 2 pp.

[16] D. Ha 2002. Personel Communitation. VIMS. Gloucester Point, VI.

[17] Frank, B. Jr. 2002. Northwest Indian Fisheries Commission unpublished green sturgeon catch data, 2 pp.

[18] Rien, T. 2002. Lower Columbia River green sturgeon catch rates from commercial landings tickets. Memorandum. Oregon Dept. of Fish and Wildlife. 14 p.

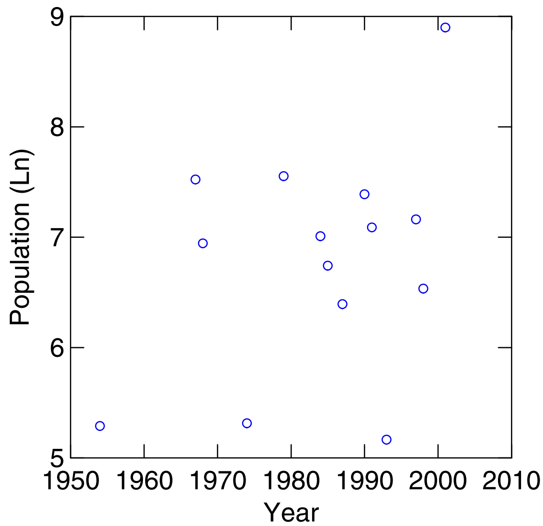

Fig. 2 CDFG San Pablo Bay green sturgeon (<102 cm) population estimates ($\log_e$ transformed) from mark and recapture white sturgeon estimates (see text) conducted intermittently from 1954 to 2001

Population abundance

Musick et al. (2000) state that green sturgeon suffered "an 88% decline in most of their range." The statement[16] comes from the fact that "the abundance of all west coast sturgeons, including green, suffered approximately an 88% decline in California, inferred from commercial catch rates (Cech 1992)." However, the only statistics in the Cech (1992) article are the reduction of all commercial sturgeon landed (white and green, but primarily white) from 1.63 million pounds in 1887 to 0.2 million pounds in 1901 an 88% reduction. If these statistics are the basis of the 88% population decline reported in Musick et al. (2000), then these claims are hard to relate to current green sturgeon status.

The only estimates of green sturgeon population size are made incidentally to white sturgeon monitoring in San Pablo Bay.[4] These estimates are calculated from a multiple-census or Peterson mark-recapture estimate of legal-size white sturgeon taken by trammel nets. The tagging experiments have been conducted irregularly since 1954, but since 1990, tagging has been conducted for 2 years consecutively and then the next 2 years are skipped. Over this period, a total of 536 green sturgeon were captured and 233 were tagged. The green sturgeon estimate was obtained by multiplying the ratio of legal-size green sturgeon to legal-size white sturgeon caught in the tagging program by the legal-size white sturgeon population estimate. There is no long-term trend in legal-size green sturgeon abundance, ($r^2 = 0.146$, slope = 0.029, $P = 0.177$, Fig. 2) even though the highest value occurred in 2001, based on linear regression[19] These estimates have a number of potential biases; the most important being the assumption of equal vulnerability of both species to the gear. Green sturgeon concentrate in estuaries only during summer and fall whereas white sturgeon may remain in estuaries year around and therefore, the temporal and spatial vulnerabilities of the two species can be very different.

Two additional green sturgeon harvest population time series were analyzed because of their length, their relative lack of bias, and their geographical importance. These were the Klamath Yurok Tribal fishery catch and catch-per-unit-effort (CPUE) series and Columbia River commercial landings. Both of these population time series came from fisheries targeting other species. The raw catch time series suffers from changing regulations and effort levels. Also, green sturgeon are not an abundant species, and therefore the numbers captured are small and variable with a large number of zero observations. Simple linear regressions were calculated for each time series providing a slope with a standard error and confidence intervals.

The Klamath Yurok Tribal fishery catch and CPUE are the most consistent green sturgeon data sets. Catch and CPUE data are available from 1984 to 2003 and it is the time series least impacted by changes in regulations.[20]Analyses were performed on $\log_e$-transformed catch and CPUE from April and May. This time period was considered to be the most representative of the green sturgeon presence in the river. The regression analyses[19] for the $\log_e$-transformed catch

[19] Undated analysis from S. Heppel and L. Hoffman. 2002. Green Sturgeon Status Assessment. Final Report for the Southwest Fisheries Science Center, Santa Cruz, CA. 41 p.

[20] D. Hillemeier. 2004. Yuork Tribe green sturgeon unpublished catch data. Yurok Tribe. Orcut, CA.

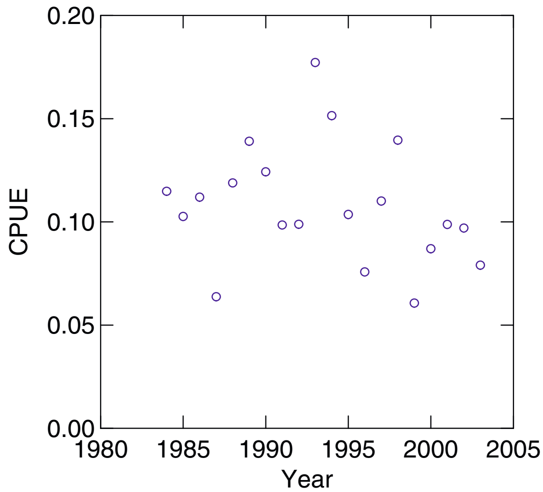

Fig. 3 Yurok Tribal green sturgeon April and May CPUE (numbers/gill net set) for 1984 to 2003 regressed against year

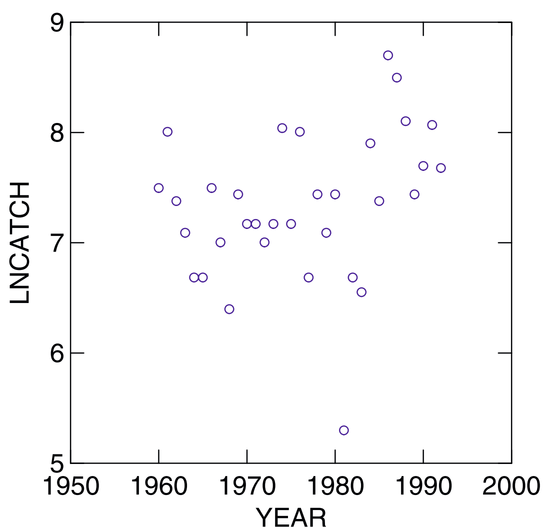

Fig. 4 Columbia River green sturgeon catch ($\log_e$ transformed) in numbers (see text) regressed against year. The time period ends in 1992 due to regulatory changes in the fishery

(r^2 = 0.494, slope = 0.053, P = 0.012) and CPUE (r^2 = 0.055, slope = –0.0008, P = 0.320, Fig. 3) both had slopes that were not significantly different from 0. Log_e transformed catch and CPUE were not well correlated with each other (r^2 = 0.166). Length–frequency data over this time period showed no trends.[1]

The Columbia River commercial landings are the longest green sturgeon time-series available and represent the largest source of removals from the population (Fig. 4). Landings were recorded in pounds in early years, but catch in numbers were estimated by Oregon Department of Fish and Wildlife (Rien et al. 2001). Fishery regulations drastically changed in 1993, so the regression was only conducted until 1992. Catch in numbers is not only affected by effort and size regulations, but also by the amount and timing of green sturgeon occurrence in the estuary during the summer. The regression analysis[19] of $\log_e$-transformed catch in numbers on years was not significant (r^2 = 0.082, slope = 0.020, P = 0.108, Fig. 4). There was a significant positive trend (r^2 = 0.083, slope = 0.022, $P < 0.0001$) when the commercial landings were adjusted for total sturgeon effort based on trip tickets[18] Length–frequency distribution of catch from 1985 to 2001 showed no trend (Rien et al. 2001).

Entrainment

Substantial numbers of green sturgeon were killed in pumping operations at state and federal water export facilities in the Sacramento-San Joaquin River Delta (Table 2). Green sturgeons taken in both water export facilities are juvenile fish in the 28 cm to 38 cm FL size range.[1] These numbers are higher in the period prior to 1986 than from 1986 to the present (CDFG 2002). For the state facility (1968–2001), the average number of green sturgeon taken per year prior to 1986 was 732; while the average number was 47 from 1986 on. For the federal facility (1980–2001), the average number prior to 1986 was 889; while the average number was 32 from 1986 on. Trends at each facility were similar with or without adjustment for volume of water pumped (per 1 000 acre-feet). Further examination of the salvage estimates founded that the actual number of actual green sturgeon observed were three-and-one/half times higher in the pre-1986 period.[21] However, a General Linear Model (GLM) analysis of the green sturgeon estimates compared to observed fish in the pre-1986 period showed that one observed fish was

[21] P. Adams, unpublished analysis. 2006. NMFS, Santa Cruz, CA.

Table 2 Green sturgeon numbers and numbers per 1000 acre-feet of water exported from the State and Federal water export facilities at the Sacramento-San Joaquin River DeltaAnnual estimates are expansions of brief sampling periods[4]

Year	State facility	Federal Facility		
	Numbers	Numbers per 1000 acre-feet	Numbers	Numbers per 1000 acre-feet
1968	12	0.0162		
1969	0	0		
1970	13	0.0254		
1971	168	0.2281		
1972	122	0.0798		
1973	140	0.1112		
1974	7313	3.9805		
1975	2885	1.2033		
1976	240	0.1787		
1977	14	0.0168		
1978	768	0.3482		
1979	423	0.1665		
1980	47	0.0217		
1981	411	0.1825	274	0.1278
1982	523	0.2005	570	0.2553
1983	1	0.0008	1475	0.653
1984	94	0.043	750	0.2881
1985	3	0.0011	1374	0.4917
1986	0	0	49	0.0189
1987	37	0.0168	91	0.0328
1988	50	0.0188	0	0
1989	0	0	0	0
1990	124	0.0514	0	0
1991	45	0.0265	0	0
1992	50	0.0332	114	0.0963
1993	27	0.0084	12	0.0045
1994	5	0.003	12	0.0068
1995	101	0.0478	60	0.0211
1996	40	0.0123	36	0.0139
1997	19	0.0075	60	0.0239
1998	136	0.0806	24	0.0115
1999	36	0.0133	24	0.0095
2000	30	0.008	0	0
2001	54	0.0233	24	0.0106

converted to 48 estimated fish (coefficient = 47.9, $F = 303$ with 16 df, $P = 0.001$). The same analysis for the period from 1986 on showed that one observed fish was converted into 9.7 estimated fish (coefficient = 9.7, $F = 12.4$ with df = 14, $P = 0.003$). So while the numbers of green sturgeon still were higher in the pre 1986 period, it appears that the expansion procedure exaggerated that difference. These entrainment estimates suffer from problems of species identification (green sturgeon were not identified until 1981 at the federal facility), and the estimates are expanded catches from brief sampling periods.[4] Additional entrainment must also occur from a large number of smaller, unmonitored water diversions on the Sacramento River.

Conclusions and discussion on the ''extinction risk'' question

Species wide threats

Ocean and estuarine green sturgeon harvest is considered a species wide threat since its impact could not be apportioned to one particular DPS (except for the Klamath tribal in-river catches). Even catches in San Pablo Bay could be fish that originated in the Northern DPS. Harvest impact could be very different if there were disproportionately high harvest of only one DPS. Current total harvest has been reduced to 6% of its 1986 value of 9065 fish. The recent reductions are due in large part to newly imposed fishing regulations in Oregon and Washington. Commercial fisheries targeting sturgeon have not been allowed in the Columbia River or Willapa Bay since 2001. Klamath tribal catch has remained relatively constant during the entire time series, but recently instituted conservations measures will decrease that catch in the future. The very recent closure of the California recreational fishery will reduce catch even further. The decrease in catch due to changes in regulations and conservations measures represents a reduction in risk to green sturgeon.

No estimates of fishing mortality or exploitation rates exist for green sturgeon, although an annual survival rate of about 85% has been suggested by examining preliminary age data for the Klamath River.[22] Secor et al. (2002) note that sturgeon populations can be harvested on a sustainable basis, but only if sufficient spawner escapement is maintained. They noted that sturgeon populations typically can not tolerate more than 5% fishing mortality during spawning runs. Similar rates of annual survival (S) have been assumed in population models for adult Gulf sturgeon in the Suwannee River, Florida ($S = 0.84$, maximum age 25; Pine et al. 2001) and age-1 + shortnose sturgeon ($S = 0.865$, max age 37; Gross et al. 2002). Higher survival rates were assumed in models for Hudson River Atlantic sturgeon ($S = 0.93$, max age 60; Gross et al. 2002) and lower Columbia River white sturgeon ($S = 0.91$, max age 100; Gross et al. 2002). Fishing mortality rates for green sturgeon are affected by slot limit regulations that restrict harvest of adults. In terms of population impacts, however, it is worth noting that sturgeon populations can be substantially affected by harvest of subadults, because of the long interval prior to maturity (Gross et al. 2002; Secor et al. 2002).

One way to judge the impact of fishing is to examine age structure and consider how many opportunities an adult sturgeon would have to spawn. This is particularly critical for sturgeon species, given that strong year classes occur infrequently and adults may only spawn every 3–5 years. Based on preliminary age data,[20] female green sturgeon in 1999–2000 Klamath River catches ranged in age from 17 to 33 although most were 25–31. Using a female maturity of age 20 and their 5 year spawning periodicity, most female green sturgeon would only spawn twice. In comparison, a restoration goal for Atlantic sturgeon (NMFS 1998) is to have at least 20 adult age classes in the spawning stock prior to any consideration of lifting the current harvest moratorium.

The northern green sturgeon DPS

The Northern DPS has two known well-established spawning populations, one in the Rogue River and one in the Klamath-Trinity River system. This spreads the risk over more than one spawning area. In addition, the two systems are not geographically close and thus do not share the same risks of catastrophic events. Spawning appears to occur infrequently in the Umpqua and Eel rivers. The principal threats to green sturgeon in this DPS are flow and temperature factors, habitat degradation, and harvest (Table 3).

The extent of green sturgeon spawning in the Rogue River has only been recently documented (Erickson et al. 2002). The river is less manipulated and habitat seems to be of better quality than in other green sturgeon spawning rivers. Blockages to migration do not seem to be limiting and habitat seems to be roughly what it was historically. Other anadromous fishes are generally doing well in the Rogue River (Weitkamp et al. 1995; Busby et al. 1996; Myers et al. 1998).

The Klamath River is considered to have the largest green sturgeon spawning population. The Yurok catch data were judged to be the most representative available population measure, since the data were based on spawning fish rather than on fish involved in their summer concentration behavior. Neither catch nor CPUE had a negative slope, but trends for both were also not statistically significant. The length data did not indicate that large fish were decreasing within the population, but sample sizes were very small. Spawning still occurs upstream to the historical limit of its habitat range (Ishi Pishi Falls). Out-

[22] R. Beamsederfer and M. Webb. 2002. Green sturgeon status review information. S. P. Cramer and Associates, Inc. Gresham, OR. 46 p.

Table 3 Historical and current spawning status of green sturgeon within the Northern DPS, including specific threats to river systems (but excluding ocean and estuarine harvest, which is considered as a coastwide threat)

River system	Historical spawning status	Present spawning status	Threats/changes
Fraser River	No evidence	No evidence[23]	Availability of appropriate habitat and degradation or alterations to the habitat (Houston 1988). Local harvest
Chehalis River	No evidence	No evidence[24]	Local harvest
Umpqua River	Known spawning	Known spawning[25]	Local harvest
Rogue River	Known spawning	Known spawning[26]	Common to Savage Rapids[23] and known to occur to Lost Creek Dam[27] Flow management and hydro effects[28] Local Harvest
Klamath River	Known spawning	Known spawning[29]	Increased temperatures[30] Reduced oxygen concentrations[31] Flow regime change[32] In-river harvest[1]
- Trinity River	Known spawning	Known spawning[33]	Reduced flows[34] See Klamath River Threats
-SF Trinity	Suspected spawning[35]	Suspected spawning[36]	1955 and 1964 floods[3] See Klamath River Threats
Eel River	Known spawnin[5]	Suspected spawning[9]	1955 and1964 floods[37] Flow management and water transfers[38] Sediment and TMDL[39]

migrant juvenile green sturgeon are captured each year in screw traps at Big Bar (Scheiff et al. 2001). There are concerns about the temperature and flow regime in the Klamath River, a major issue for salmonids that have been highlighted by recent fish kills (NRC 2004).

The Trinity River has far less data than the Klamath. The Hoopa Tribe has a small in-river

[23] Fraser River green sturgeon are from U.S. spawning populations, but do occur as far north as the Skeena River (D. Lane. 2004. Malaspina University, Nanaimo, British Columbia.

[24] Washington Department of Fish and Wildlife. 2004. Letter to Mr. James Lecky from R. Fuller, 4 pp.

[25] T. Rien. 2004. Oregon Department of Fish and Wildlife. Clackamas, OR. Two juvenile green sturgeon (approximately 10 cm long) were regurgitated from two smallmouth bass caught at rkm 134 on the Umpqua River, in June 2000.

[26] Erickson et al. (2002).

[27] R. Reisenbichler. 2004. U. S. Geological Service. Seattle, WA.

[28] Oregon Department of Fish and Wildlife. 2002. NMFS Status Review for North American Green Sturgeon. ODFW Memorandum, 5 pp.

[29] Spawning to Ishi Pishi Falls (Moyle 2002). Juveniles taken annually at Big Bend (Scheiff et al. 2001).

[30] Increased summer temperatures due to lower flows (NRC 2004).

[31] Oxygen concentration decreased due to flow and degradable organic material below Irongate Dam (NRC 2004).

[32] Shift in peak flows from April to March (NRC 2004).

[33] Spawning to Greys Falls (Moyle 1992). Juveniles taken in most years at Willow Creek (Scheiff et al. 2001).

[34] Trinity River flows reduced 88% (NRC 2004).

[35] 1978 CDFG Letter (referenced in USFWS 1981, Klamath River fisheries investigation program, Annual Report—1980 Arcata, CA, 105 pp, but not located).

[36] Willow Creek trap located down stream of S.F. Trinity confluence (Scheiff et al. 2001)

[37] Historic reductions to chinook populations from which they never recovered (Moyle 2002).

[38] Summer flows are lower and decrease earlier than historical flows (National Marine Fisheries Service. 2002. Biological opinion for the proposed license amendment of the Potter Valley project. Southwest Region. Long Beach, CA. 135 pp).

[39] Loss of habitat due to sedimentation from land use practices and large scale floods (NMFS 2002).

Table 4 Historical and current spawning status of green sturgeon within the Southern DPS, including specific threats to river systems (but excluding ocean and estuarine harvest, which is considered as a coastwide threat)

River system	Historical spawning status	Present spawning status	Threats/changes
Sacramento River	Known spawning	Known spawning[1]	Impassible barriers (Keswick and Shasta dams)[21] Adult migration barriers[40] Insufficient flow[21] Increased temperatures[41] Juvenile entrainment[1] Exotic species (e.g., striped bass)[4] Poaching[1] Pesticides and heavy metals[21] Local Harvest
Feather River	Suspected spawning[4]	No evidence[11]	Impassible barriers (Oroville Dam)[42] See Sacramento River Threats
San Joaquin River	No evidence[1,43]	No evidence[11]	Impassible Barriers (Friant Dam)[44] Extreme low flow[45] See Sacramento River Threats

fishery that takes less than 30 adult green sturgeon each year (Table 1). Juvenile out-migrant green sturgeon are captured in most years in small numbers at Willow Creek (Scheiff et al. 2001). There are similar concerns about the temperature and flow regime here as there are in the Klamath (NRC 2004).

The Eel River is the southern most known spawning area in the Northern DPS. Moyle (2002) suggested that green sturgeon were lost from the Eel River following the 1964 flood. This event along with the 1955 flood and poor land use practices brought large amounts of sediment into the Eel River, and this high sediment level is present today. Some portion of the deep holes that green sturgeon use for holding must have been filled in by these events, but the extent is unknown. Green sturgeon do not appear to be extirpated from the Eel River since there were sightings of adults in both 1995 and 1996 and juveniles in the estuary in 1994. The adult surveys were only conducted in those years and the estuary surveys were only conducted in one other year. Nevertheless, green sturgeon are almost certainly severely reduced in the Eel River from historical levels.

Green sturgeon in the Northern DPS are not considered in danger of extinction now nor are they likely to become endangered in the foreseeable future throughout all of their range, although the lack of data introduces a great deal of uncertainty into this decision. The risk of catastrophic events is spread over a larger geographically area in this DPS, because there are two known spawning populations in the Rogue and Klamath-Trinity rivers. Population trends are not

[40] Other barrier that are not impassible, RBBD and ACID. Also, sturgeon attracted to stranding areas such as Yolo Bypass. J. McLain. 2004. NOAA Fisheries, Sacramento, CA.

[41] High water temperatures previous to winter-run chinook flow management (J. McLain. 2004. NOAA Fisheries, Sacramento, CA.

[42] No evidence of spawning but continued presence of green sturgeon in the Feather and Yuba rivers suggest that they are trying to migrate into presumed spawning areas now blocked by Oroville Dam.

[43] Adult presence documented in Delta.[1] Evidence of white sturgeon spawning in San Joaquin.[11] Accounts of unspecified sturgeon sport catch in San Joaquin River as far as the Merced River (Kohlhorst 1976).

[44] San Joaquin River and tributaries block by dams (Yoshiyama et al. 2001).

[45] Vernalis flows as low as 17% of minimum targets. J. McLain. 2004. NOAA Fisheries, Sacramento, CA.

negative and harvest has been reduced. Green sturgeon populations in this DPS face serious potential threats (Table 3) that are particularly worrisome given the lack of data to adequately monitor population status. We recommend that appropriate monitoring of these populations be implemented so that a serious decline in population status could be detected in a timely manner.

The southern green sturgeon DPS

Green sturgeon face a larger number and severity of threats in the Southern DPS (Table 4). The principal threat to this DPS comes from the reduction of green sturgeon spawning to a single area in the Sacramento River. The Sacramento River has impassible barriers blocking green sturgeon access to what were almost certainly historical spawning grounds upstream from Shasta and Keswick dams constructed in the 1940's and 50's.[46] The same is also true for Feather River and Oroville Dam,[47] completed in 1968.[48] In addition, there are also other migration barriers such as Red Bluff Diversion Dam (RBDD) and Anderson-Cottonwood Irrigation District Dam that do not complete block migrations or only block fish seasonally. The Sacramento River now has both reduced and controlled flow.[21] A strong correlation has been found between mean daily temperature and white sturgeon year-class strength.[21] Similar relationships may exist for green sturgeon. High temperatures may be less of a problem that it once was due to the installation of the Shasta Dam temperature control device in 1997, although Shasta Dam has a limited storage capacity and cold-water reserves could be depleted in long droughts. Temperatures at RBDD have not been higher than 16 °C since 1995. This is near green sturgeon egg and larvae optimal temperatures of 15–19 °C (Mayfield and Cech 2004). However, green sturgeon reproduction before 1995 probably was adversely affected by temperature. This may have caused population reductions that could still affect the overall population size and age-structure even now. The average number of juvenile green sturgeon entrained at both the state and federal facility prior to 1986 were higher than they were from 1986 on. There are no apparent reasons for the large reduction in numbers entrained. Exotic species are an ongoing problem in the Sacramento-San Joaquin River and Delta systems (Cohen and Carlton 1998). Probably, the largest problems with exotic species regard the replacement of native food items. The exotic bivalve *Potamocorbula amurensis*, introduced in 1988, has become the most common food of white sturgeon and was found in the only green sturgeon examined.[4] Moreover, the overbite clam is known to bioaccumulate selenium, a toxic metal (Linville et al. 2002). Green sturgeon may also experience predation by introduced species including striped bass. Sturgeon have high vulnerability to fisheries and the trophy status of large white sturgeon makes them the target of poachers.[4] Green sturgeon are caught incidentally in these white sturgeon fisheries and may also be taken in illegal fisheries. Pollution within the Sacramento River increased substantially in the mid-1970s when application of rice pesticides increased.[21] Estimated toxic concentrations for the Sacramento River during 1970–1988 may have deleteriously affected striped bass larvae (Bailey 1994). White sturgeon may also accumulate PCB and selenium,[49] substances know to be impair embryonic development.

The Sacramento River supports the only known green sturgeon spawning population in this DPS. There has almost certainly been a substantial loss of spawning habitat behind Keswick and Shasta dams.[21] The historical habitat data has been

[46] U.S. Fish and Wildlife Service. 1994. Recovery Plan for Sacramento-San Joaquin Native Fishes. Portland, OR. 142 p.

[47] U.S. Fish and Wildlife Service. 1995. Working Paper on Restoration Needs: Habitat Restoration Actions to Double Natural Production of Anadromous Fish in the Central Valley of California. Vol. 3. Prepared for the U. S. Fish and Wildlife Service under the direction of the Anadromous Fish Restoration Program Core Group. Stockton, CA. 544 p.

[48] California Data Exchange Center. http://cdec.water.ca.gov/. California Department of Water Resources, Division of Flood Management. Sacramento, CA.

[49] J. White, P. Hoffmann, K Urquahart, D. Hammond, and S. Baumgartner. 1989. Selenium verification study, 1987–1988. A report to the California State Water Resources Control Board from the California Department of Fish and Game, April 1989. 60 p.

summarized in Lindley et al. (2004). Green sturgeon occur up to the impassible barrier at Keswick Dam. It is unlikely that green sturgeon historically reproduced in their current spawning area based on the historical temperature regime that occurred before the construction of Shasta and Keswick dams. At the present, water temperatures in the current spawning area are lower due to cool-water releases from Shasta Dam. Green sturgeon almost certainly spawned further up the mainstem that they do now. It possible that the additional habitat behind Shasta Dam in the Little Sacramento, Pitt, and McCloud systems would have supported separate populations or at least, a single larger population that was less vulnerable to catastrophes than the current one.

Green sturgeon almost certainly no longer spawn in the Feather River. Access to a substantial amount of habitat in the Feather River was lost with the construction of Oroville Dam. California Department of Fish and Game concluded that the Feather River spawning habitat was most likely lost due to habitat blockage by Oroville Dam and from thermal barriers created by the Thermaltio Afterbay facility.[4] U.S. Fish and Wildlife Service stated[17] that ‘‘Evidence also suggests that sturgeon reproduction occurs in both the Feather and Bear rivers.’’ in reference to white sturgeon prior to dam construction. Again, it must be assumed that a similar conclusion could be made for green sturgeon in the face of the paucity of data. Sturgeon (including some documented green sturgeon) still regularly occur in the Bear and Yuba rivers[4,11] and therefore must migrate through the Feather River. Threats to green sturgeon are similar to those faced in the Sacramento River.

There is not sufficient information to establish whether the San Joaquin River system ever had supported a viable green sturgeon population. There is no evidence of green sturgeon occurrence or spawning in the San Joaquin River.[1,4,11] White sturgeon do occur in the San Joaquin River system, particularly in wet years[4] and the first record of white sturgeon spawning in the San Joaquin system was made in 2003.[11] Moyle (2002) suggests that green sturgeon reproduction may have taken place in the San Joaquin River because adult green sturgeon were captured at Santa Clara Shoal and Brannan Island Recreational Area in the Delta. If green sturgeon occurred in the San Joaquin system, the potential threats would be similar in nature to those faced in the Sacramento River, but would probably be more extreme.

The green sturgeon Southern DPS population trend information was less definitive than in the Northern DPS, and less convincing. The San Pablo Bay population estimates had a slightly positive trend, which was not statistically significant, even though the 2001 estimate was the highest on record. The usefulness of these estimates was reduced because they are based on the green sturgeon’s summer concentrations, a situation which is not understood. In addition, unequal vulnerabilities to sampling gear of these two species make these estimates less reliable.

Green sturgeon in the Southern DPS are likely to become an endangered species in the foreseeable future. The Southern DPS is at substantial risk, primarily because green sturgeon are confined to a single spawning area in the Sacramento River. Potential threats faced by green sturgeon are substantially greater in the Southern DPS than in the Northern one. Threats in this DPS include vulnerability due to concentration of spawning, smaller population size, lack of population data, potentially growth-limiting and lethal temperatures, harvest concerns, loss of spawning habitat, entrainment by water projects and influence of toxic material and exotic species. Catastrophic events have occurred in this DPS, such as the large-scale Cantara herbicide spill which killed all fish in a 10-mile stretch of river upstream from Shasta Dam, and the 1977–1978 drought that caused year-class failure of winter-run chinook salmon. Population sizes are unknown in this DPS, but are clearly much smaller than in the northern one and therefore this DPS is much more susceptible to catastrophic events. As is the case for the Northern DPS, the Southern DPS is in need of adequate population monitoring.

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