CALIFORNIA DEPARTMENT OF FISH AND GAME COMMENTS TO NMFS REGARDING GREEN STURGEON LISTING

Executive Summary

On December 14, 2001, in the Federal Register, the National Marine Fisheries Service (NMFS) published its 90-day finding that a petition to list green sturgeon (*Acipenser medirostris*) as threatened or endangered presented substantial scientific information indicating that the petitioned action may be warranted. As part of its status review, the NMFS solicited information and comments pertaining to green sturgeon. These California Department of Fish and Game (CDFG) comments are in response to that solicitation.

Our comments contain all information to which we have access concerning green sturgeon in California. We have made use of data from various units of CDFG and well as relevant published material, both primary and gray literature. We discuss green sturgeon range and distribution, migrations, size and age structure, habitat use, abundance, harvest, habitat impacts, and present and planned conservation actions.

For the Sacramento-San Joaquin system, we present 1) data from a tagging program of mostly legal-sized fish conducted intermittently since 1948; 2) fish facility salvage data from 1968 to present; 3) trawl, gill net, fyke trap, seining, and set-line catches from surveys starting as early as 1980; 4) juvenile catches at the Glenn-Colusa Irrigation District diversion on the Sacramento River since 1988, 5) length and age data from green sturgeon collected in 1965-1976; 6) records from green sturgeon catches by the Delta Fish and Wildlife Protection Study in 1962-1964; and 7) records from the U.S. Fish and Wildlife Service (USFWS) of adult and young-of-the-year sturgeon observed in the vicinity of Red Bluff Diversion Dam on the Sacramento River.

For the Klamath River system, we present 1) seining data for adults and juveniles from the upper estuary from 1977 to 1990 and 2) records from CDFG and USFWS catches, observations, and tribal harvest calculations on the Klamath, Trinity, and Salmon rivers as early as 1968.

Information on the Eel River and on other coastal bays and rivers is extremely limited. On

the Eel River, we present records and observations of CDFG personnel from as early as 1967. Tagging data from Arcata Bay in 1956 and 1992-1993 are presented.

We also comment on some of the petition's conclusions with respect to green sturgeon in California, finding that a general recent (last 30-50 years) decline in green sturgeon abundance cannot be documented with available data; that estimated harvest rates are low (although based on meager data); that dams, with the exception of Red Bluff Diversion Dam and, possibly, Oroville Dam, may not have had much effect on available spawning habitat; and that present angling regulations and fishing closures provide substantial protection to green sturgeon.

The Interagency Ecological Program for the Sacramento-San Joaquin Estuary may provide more data and additional analysis for green sturgeon in the Central Valley, but this likely will not be available until after the March 14, 2002 deadline for submittal of comments.

Introduction

On June 12, 2001, the Environmental Protection Information Center, the Center for Biological Diversity, and WaterKeepers Northern California jointly submitted a petition to the National Marine Fisheries Service (NMFS) to list the green sturgeon (*Acipenser medirostris*) as either threatened or endangered under the federal Endangered Species Act (ESA).
The petitioners justify their request based, generally, on the following assertions:

1) Green sturgeon have experienced a severe recent decline in overall abundance. An article in *Fisheries*, an American Fisheries Society publication, described the green sturgeon as endangered and indicated that it has declined 88% in most of its range.
2) Only two or three spawning populations remain, and probably 80-90% of all green sturgeon spawn in the Klamath River. More former spawning populations have been extirpated in the past century than currently remain in existence. The remaining spawning populations all occupy rivers with flow regimes affected by water projects.
3) The three spawning populations probably contain a few hundred mature females, at best and it is likely that the Klamath and Sacramento spawning populations would be classified as separate Evolutionarily Significant Units if adequate genetic information were available.
4) The green sturgeon may have certain unique depensatory mortality factors that take an increasing percentage of progressively smaller populations, dooming them to extinction.
5) Present fisheries (especially a commercial fishery in the Columbia River and Washington coastal region and the developing tribal gill net fishery on the Klamath River) continue to deplete a stock of large, old fish. It is likely that fishing pressure on green sturgeon has been increasing as Pacific salmon and white sturgeon (*Acipenser transmontanus*) stocks decline.
6) The principal fisheries for green sturgeon occur in a region with no evidence of

sturgeon spawning and, thus are exploiting fish produced elsewhere.

We know less about green sturgeon than any other North American sturgeon species and all other sturgeon species, except white sturgeon, are considered to be threatened in one way or another.

7) The sport fishery slot limit in California does not offer adequate protection to large and fecund female green sturgeon.

On December 14, 2001, the National Marine Fisheries Service (NMFS) published its 90-day finding on the petition in the Federal Register. The NMFS found that the petition presented substantial scientific information indicating that the petitioned action may be warranted and will conduct a status review of the green sturgeon to determine if the petitioned action is warranted. To this end, NMFS solicited information and comments pertaining to green sturgeon. These California Department of Fish and Game (CDFG) comments are in response to that solicitation.

The comments provided here contain all information to which we have access concerning green sturgeon in California. We have made use of data from various units of CDFG and well as relevant published material, both primary and gray literature. We discuss green sturgeon range and distribution, migrations, size and age structure, habitat use, abundance, harvest, habitat impacts, and present and planned conservation actions. We also comment on some of the petition's conclusions.

We anticipate that others with information about green sturgeon in California will respond to the NMFS request for comments and provide data not available to the CDFG. These include researchers at the University of California, Davis (UCD) (e.g., genetic differentiation of populations, physiology, reproductive biology), the U.S. Fish and Wildlife Service (USFWS) Fisheries Research Assistance Offices in Arcata and Red Bluff (e.g., Klamath River harvest, spawning locations, and age structure; upper Sacramento River occurrence of juveniles and spawning areas), and the Klamath and Trinity River tribes (harvest and size and age structure). Also, the Interagency Ecological Program for the Sacramento-San Joaquin Estuary may provide more data and additional analysis for green sturgeon in the Central Valley, but this likely will not be available until after the March 14, 2002 deadline for submittal of comments.

Range, Distribution, and Migration

Sacramento-San Joaquin System

Adults

Information on adult green sturgeon distribution and migration is available from the CDFG tagging program, from a CDFG telemetry study, and from incidental observations and anecdotal reports.

Tagging - Although we have discovered some tagging records for green sturgeon as early as 1948, the present ongoing large-scale CDFG sturgeon tagging program did not begin until 1954, when the sport fishery reopened. It has continued intermittently since then, most recently by tagging in 2 successive years, skipping 2 years, then tagging again for 2 years. This pattern is designed to provide the most reliable estimates of mortality rates and abundance.

Sturgeon are captured in trammel nets in San Pablo Bay in the fall and tagged using disk-dangler reward tags. Sturgeon are identified to species, measured and release location, tagger, date, and condition of the fish recorded. Reported recoveries of tagged fish from the fishery are used to determine distribution and migrations of Sacramento-San Joaquin system green sturgeon.

From 1954 to 2001, 233 green sturgeon have been tagged in the estuary (Table 1; Appendix A); 17 (7.3%) of these have been recovered, mostly from commercial fisheries (13) (Table 2). Two of the recoveries came from the Sacramento-San Joaquin Estuary, a fish tagged in 1967 and recovered over 3 years later in San Pablo Bay and a 116-cm fish tagged in 1984 and recovered 83 days later in San Pablo Bay. A 124-cm green sturgeon tagged in 1985 was recovered shortly after tagged and probably also came from the estuary. Two recoveries have come from the Pacific Ocean off California, one from Monterey Bay and the other from Bodega Head. The majority of the recovered tagged green sturgeon (12) have come from commercial fisheries in Oregon (7) and Washington (5). Eight of these recoveries were from the Columbia River (or vicinity), mostly in late summer. Three recoveries were from the vicinity of Grays Harbor, Washington and one was from Winchester Bay, OR.

In 1948 and 1949, apparently incidental to other CDFG tagging studies (probably of striped bass), tags of an unknown type were applied to 42 green sturgeon as small as 59 cm TL (Table 1, Appendix A). All except one fish captured in the Sacramento River at Broad Slough were caught and tagged in San Pablo Bay. Records indicate that only one of these fish was

subsequently recovered: a 65-cm fish from Monterey Bay, 197 days after being tagged (Table 2).

These tagging data, although sparse, indicate that legal-sized green sturgeon found in San Pablo Bay in the fall make extensive ocean migrations and spend much of their lives in the ocean or in Oregon and Washington estuaries (primarily the Columbia River and Grays Harbor estuaries). The recovery of one tagged fish from San Pablo Bay after 3 years at large suggests that some sub-adult green sturgeon remain in the Sacramento-San Joaquin Estuary for extended periods or move back into the estuary after years in the ocean. We know of no green sturgeon tagged in the Columbia River or other areas in Washington or Oregon that has been recaptured in California, so our knowledge of the extent of movement among these areas is based solely on fish tagged in the Sacramento-San Joaquin Estuary.

Telemetry - The CDFG attached external radio-tags to 30 sturgeon each year in 1990 and 1991 (Schaffter 1997). These fish were captured in baited set-lines fished in the Sacramento River between Hood and Freeport during late winter and spring of these 2 dry years. Of the 60 fish radio-tagged, only one was a green sturgeon. This 184-cm fish was tagged on March 7, 1991. It was only located once, 7 days after tagging, at which time it had moved upstream to river kilometer (rkm) 107, above the mouth of the American River (rkm 97), but still well downstream of the mouth of the Feather River (rkm 128). Obviously, this one fish does not provide much information concerning adult green sturgeon movements in the Sacramento River.

Incidental observations and anecdotal reports - U.S. Fish and Wildlife Service personnel observed sturgeon while electrofishing for winter-run chinook salmon (*Oncorhynchus tshawytscha*) below Red Bluff Diversion Dam from 1989 to 1991. Between April 3 and May 21, 1991, they observed 19 fish identified as green sturgeon (presumably adults) (Appendix B). One of these was dead in shallow water and was photographed and had a pectoral fin removed. The accuracy of identification of the other 18 fish is unknown, but the observers were familiar with the differences between white and green sturgeon. The only evidence that makes these identifications suspect is the fact that green sturgeon were only reported in 1991; 28 fish observed in 1989 and 1990 were all described as white sturgeon. Numerous adult sturgeon have been observed in the vicinity of RBDD since 1991 by USFWS personnel (K. Brown, USFWS, pers. comm.)

In 1993, Patrick Foley (University of California, Davis [UCD]; pers. comm.) found

evidence of the occurrence of adult green sturgeon in the Feather River. This evidence was in the form of photographs in an area bait shop(s) and anglers' descriptions of catching green sturgeon in the Feather River. Subsequent contacts by CDFG of bait shops along the Feather River in spring 2000 yielded no information that sturgeon had been caught in that river recently. Possibly, green sturgeon only use (spawn in?) the Feather River in very high flow years like 1993 and avoid the river in low flow years (see section on spawning habitat use in the Sacramento-San Joaquin system).

Juveniles

Information on the distribution of juvenile green sturgeon is available from USFWS catches of young-of-the-year fish at Red Bluff Diversion Dam, catches at the Glenn-Colusa Irrigation District fish screens, San Francisco Bay Outflow Study otter and midwater trawl catches, and sampling in the estuary for juvenile sturgeon using gill nets, otter trawls, set-lines, and trammel nets.

Upper Sacramento River - Larval and juvenile sturgeon have been caught in traps at two sites in the upper Sacramento River: below the Red Bluff Diversion Dam (RBDD) (rkm 391) and from the Glenn-Colusa Irrigation District (GCID) pumping plant (rkm 330). The sampling history extends from January 1995 through July 2000 at RBDD and from 1986 through 2001 at GCID. All sampling at RBDD was with rotary-screw traps. Before 1991, sampling at GCID was with a fyke trap and sturgeon catches were only recorded during June-August. In those years the fyke trap was in the bypass channel and operated only during the irrigation season. Starting in 1991, a rotary-screw trap was used to sample year-round (with the exception of 1998, when no sampling occurred) in the intake channel, where it was no longer dependent on diversion of water by the pumping plant; thus, sturgeon catches were recorded over a longer time period.

For purposes of these comments, we assumed that larval and post-larval sturgeon captured in this upper reach of the Sacramento River were green sturgeon. Although only larger specimens (generally >150 mm TL) have been directly identified as green sturgeon, larval fish from RBDD (n = 124) and GCID (n = 12) that have been grown out at the UCD to a size sufficient for species identification have all been identified as green sturgeon (P. Foley, UCD, in

a 1994 letter to Nick Villa, CDFG; Gaines and Martin 2001).

Sturgeon larvae first appear in RBDD catches from early May to early July at lengths ranging from 24 to 31 mm FL. Timing of peak catches has varied annually, but has always occurred in either June or July (Figure 1). Migration of most young-of-the-year fish past RBDD is over by the end of August. At this time, young-of-the-year migrants have ranged from 32 to 70 mm FL (Gaines and Martin 2001). Sturgeon catches were highest during 1995 (as high as 0.08 fish/acre-foot) and declined to <0.01 fish/acre-foot in 1999 and 2000 (Figure 1). Some green sturgeon rear to larger sizes above RBDD, or move back there after spending time downstream; two sturgeon between 180 and 400 mm TL were captured in the rotary-screw trap during 1999 (Figure 1) and green sturgeon within this size range have been impinged on diffuser screens associated with a fish ladder at RBDD (K. Brown, USFWS, pers. comm.).

Since continuous sampling started in 1991, larval and post-larval sturgeon have first appeared at GCID as early as May 2 (in 2001) and as late as June 25 (in 1991) (Appendix C). As at RBDD, catches of larvae peaked during June and July (Table 3). Some late spawning of green sturgeon is suggested by catches of 34-36-mm larvae in October 1997, 1999, and 2000. Larger juvenile sturgeon ($\geq$100 mm) have been caught in July and during fall (Appendix C).

Catches of sturgeon larvae at GCID from 1991 to 2001 have been highly variable, ranging from 23 (1994) to over 700 (1993) (Figure 2). Catch trends at GCID were similar to those at RBDD in some years, i.e., moderately high in 1995-1997 and low in 2000.

San Francisco Bay Outflow Study - The Bay Study samples monthly with otter and midwater trawls in much of the estuary, starting in the Sacramento River above Rio Vista and in the San Joaquin River at Prisoners Point and going downstream through South San Francisco Bay. It has captured only 61 juvenile sturgeon since it started in 1980. They have ranged in size from 20 to 112 cm TL and have been captured throughout the estuary; however, the majority (42 fish) have been taken from Carquinez Strait upstream through the delta (Table 4). The other green sturgeon came from San Pablo Bay (10 fish), and San Francisco Bay (9 fish). Most (48 fish) juvenile green sturgeon were caught between April and October.

Juvenile sampling - The earliest information on juvenile green sturgeon distribution in the estuary is from the Delta Fish and Wildlife Protection Study. These results were published in 1966 as CDFG Fish Bulletins 133 and 136. Ganssle (1966) caught 34 juvenile green sturgeon

from 25 to 74 cm in gill nets and otter trawls in Suisun and San Pablo bays between January 1963 and December 1994. His greatest gill net catch was in September in San Pablo Bay; otter trawl catches showed no pattern of distribution.

Similar sampling in the delta between September 1963 and August 1964 collected 138 juvenile green sturgeon in gill nets and 28 in an otter trawl (Radtke 1966). Highest catches were in gill nets fished during the summer in 1-3 m of water on shoals in the lower San Joaquin River. Green sturgeon caught during this survey ranged from about 20 to 58 cm FL.

More recently, the CDFG has been sampling sturgeon from the delta downstream to San Pablo Bay with a variety of gear since 1988 in an attempt to assess year-class strength of white sturgeon. The gear has included set and drift gill nets (1988-1989), otter trawls (1989-1990) and baited set-lines (1991-2001). All gear was designed to target sublegal fish (<117 cm).

Only 20 juvenile green sturgeon have been caught in these surveys (One 169-cm adult was caught by set-line gear in Broad Slough in 2000.) (Table 5) and 17 of those were caught in gill nets when they were fished in 1988-1989. The juvenile green sturgeon ranged in size from 32 to 122 cm and were found throughout the sampling are that started in the western delta and extended downstream into mid-San Pablo Bay.

Salvage - Collection of juvenile green sturgeon at the fish facilities associated with the export pumps in the south delta indicates that they occur there, either naturally or as the result of reverse net flows in the central and south delta (Appendix D). Estimated salvage of green sturgeon is discussed further in other sections of these comments.

Also associated with water exports from the south delta are observations of green sturgeon in Kodiak seine catches in Clifton Court Forebay in 1992-1993. This seining was part of an experiment to reduce predation on young fish in Clifton Court Forebay by removing predators, mainly striped bass. From November 30, 1992 to March 1,1993, seining captured 42 green sturgeon from 42 to 185 cm FL (Appendix E). It is likely that these fish are not trapped in Clifton Court Forebay, but can move in and out through the radial gates at Old River when flow velocities through the gates are suitable. Tagging studies of striped bass in the forebay have shown this type movement to be common.

Incidental Observations - Juvenile green sturgeon have been captured infrequently during CDFG striped bass tagging in the spring. Striped bass are captured for tagging in drift gill nets

in the western delta and in fyke traps in the Sacramento River. We have recorded sturgeon catches since 1989 in gill nets and since 1974 in fyke traps. Gill nets caught 20 green sturgeon in 5 different years between 1989 and 2000; 15 of these were captured in 1 year (1994) and 14 were collected in April. (Appendix F). Fyke traps caught only 6 green sturgeon in 5 different years between 1974 and 2000. Two of these were caught before 1990, when the fyke traps were moved from Clarksburg to Knights Landing, and four were caught from 1990 to 2000. Four of the six fish were caught in April.

Juvenile green sturgeon <117 cm TL have been reported to be commonly caught by anglers in specific areas of southwestern San Pablo Bay in recent years (G. Hough, FV Morningstar skipper, pers. comm.)

Klamath River System

Adults

The Klamath River is accessible to adult green sturgeon up to Ishi Pishi Falls (Klamath rkm [Krkm] 107) and green sturgeon adults have also been observed in the lower 8 km of the Salmon River which joins the Klamath at Krkm 106 (Moyle and Yoshiyama 1992). Spawning probably occurs in the immediate area of Ishi Pishi Falls, but young-of-the-year fish have not been confirmed upstream of Big Bar (Krkm 80) (USFWS 1998). Adult sturgeon ascend the Trinity River to Gray's Falls (Trinity rkm [Trkm] 69), but no confirmation of spawning, as evidenced by juvenile capture, has occurred upstream of Trkm 40 (Healey 1973).

Mature green sturgeon usually enter the Klamath River in late March to mid-April with the peak migration in mid-April to mid-May. (USFWS 1982). Male:female ratios ranged from 1.1:1 to 2.4:1 in 1980-1982 (ibid.). Most adult green sturgeon are captured during the spring salmon gill net fishery (April-July), but a substantial portion of the adult harvest occurs after August, especially in the estuary and lower 10 km of the river.

Juveniles

Young-of-the-year (YOY) emigration from upriver spawning areas in the Klamath-Trinity system, as measured by fyke nets in the Trinity River (Healey 1973) and rotary-screw traps in

the Klamath River (USFWS 1998, 1999) begins between mid-May and July. Healey (1973), sampling in the Trinity River at Willow Creek (Trkm 40), captured YOY green sturgeon from July to September, 1968. The USFWS, sampling with a rotary-screw trap at Big Bar on the Klamath River (Krkm 80) caught YOY green sturgeon starting from mid-May (1994) to mid-June (1995-1996); catches continued through mid-July. Two juvenile sturgeon between 15 and 20 cm long were observed in the lower 10 km of the Salmon River during October 1996 (J.B. Grunbaum, U.S. Forest Service, Happy Camp, CA. Memo dated Dec. 10, 1966).

Young-of-the-year and yearling green sturgeon are found in the upper portion of the Klamath River estuary. Most green sturgeon captured during CDFG seining for adult salmon and steelhead (*Oncorhynchus mykiss*) from August to early October 1984-1990 between Krkm 4 and 6 were either YOY or age 1 fish (12-46 cm FL; see growth curve in Figure 51, USFWS 1983). During 1984-1990, when sampling effort was recorded, catch per seine haul ranged from 0.047 in 1984 to 0.472 in 1987 (Figure 3), suggesting that green sturgeon production in the Klamath River can vary annually by at least an order of magnitude. Juveniles >420 mm TL have not been observed upstream of tidal influence (R.A. Adair. Green sturgeon characteristics in the Klamath River, California. Unpublished manuscript, USFWS, Arcata, CA).

Immature green sturgeon between 50 and 130 cm TL and classified as coastal marine migrants enter the Klamath River estuary from July through November and inhabit the lower 6 km of the river (USFWS 1985). An increasing size distribution of this population between 1979 and 1981 led the USFWS (1982) to hypothesize that they were sampling a strong year class of Klamath system origin that was growing over time, implying that coastal migrants were of local origin.

Eel River

Adults

Adult (1.5-2.0 m) green sturgeon were observed in the Eel River between rkm 100 and rkm 160 by CDFG biologists while conducting other surveys in 1995, 1996, and 1997. In 1995, sturgeon were observed during April (1 fish), September (4), and November (1) and in 1996 and 1997, during August (1 fish each year). All but one of these fish were in Humboldt County and

were legally protected from capture by the sturgeon fishery closure (Scott Downie, CDFG, pers. comm.). It is also felt by CDFG enforcement personnel that poaching of sturgeon is less than in the past because of reduced human population in this reach of the Eel River due to declines in the timber industry (ibid.).

Juveniles

Puckett (1976) reported capturing juvenile green sturgeon during a survey of juvenile anadromous fishes in the Eel River system from 1967 to 1970. Sampling sites included six locations on the mainstem between Rio Dell (rkm 20) and Dos Rios (rkm 191). The South Fork Eel River below Benbow Dam was not sampled. The primary sample gear was a 3.6-m-long funnel net of mesh graduating from 3.8 to 1.3 cm stretched measure and terminated by a live box. The mouth opening was attached to a 0.7 x 1.5-m pipe frame. The net was held in place by a bridal attached to stakes driven into the river bed, or, at two locations during higher flows, from bridges with a truck-mounted winch. Sampling was sporadic at most sites, but most frequent (although still <5 days/month) for spring through fall sampling at McCann (rkm 76) during 1968-1970 and Fort Seward (rkm 109) during 1968 (Table 6).

Limited length information indicates that juvenile green sturgeon captured in May were <70 mm; those captured in June were 70-140 mm; and those captured in July, 80-130 mm. There have been no formal investigations of sturgeon in the Eel River since this study.

There is evidence of successful green sturgeon spawning in the Eel River during the mid-1990s. Two juvenile green sturgeon, 282 mm and 510 mm FL were taken from the upper estuary of the Eel River in July and October 1994 (Steve Cannata, CDFG, pers. comm.). These lengths would correspond to age 1 and 2 green sturgeon, typical lengths found in the Klamath River estuary (Nakamoto and Kisanuki 1995).

Other Coastal Rivers and Bays

In August 1956, Ed Best of the CDFG Marine Fisheries Division tagged 50 green sturgeon captured in an otter trawl in Arcata Bay (Appendix G). Green sturgeon were again tagged in Arcata Bay in 1992 and 1993, apparently by CDFG and Humboldt State University personnel.

In both instances, fish were probably captured in bottom trawls. We have no record of recaptures from any of these fish, so they provide no information on green sturgeon movements or distribution other than to document the apparent common occurrence of sub-adult and adult fish in Humboldt Bay.

Other evidence of green sturgeon in the Humboldt Bay system can be found in several reports describing the status of the species. As an example, Moyle et al. (1992) refer to several sources that report green sturgeon from Humboldt or Arcata Bay between the early 1970s and 1989.

Size and Age Structure

Sacramento-San Joaquin System

Information on size and age structure of green sturgeon in the Sacramento-San Joaquin System is available for fish captured during tagging, set-lining, gill netting, trawling, party boat sampling, larva sampling, striped bass tagging, and from catches at the Glenn Colusa Irrigation District intake and by the USFWS at Red Bluff Diversion Dam. Most of these fish were not aged, but age of fish captured after their first year of life can be inferred from an age-length key (Table 7) developed from 150 aged fish collected by a variety of methods from 1965 to 1976 (Appendix H). Most of these fish were juveniles, so this key only includes fish up to age 9 and 119 cm TL. The small sample size and difficulty of interpreting age of green sturgeon from pectoral fin ray cross sections (Three readers could seldom agree on the age of individual fish.) suggest that this age-length key has limited utility. Nevertheless, it can be used to assign ages to fish that have only been measured.

More recent age data from the Sacramento-San Joaquin System is not presently available, but fin rays were collected from 133 green sturgeon captured during tagging in 2001. These will be sectioned and read in 2002.

Tagging

We have records of the lengths of 643 green sturgeon captured during tagging since 1948

(Appendix I). From 1948 to 1954, it appears that most sturgeon captured, regardless of size, were measured and tagged; in 1967-1968, only legal-sized fish were measured and tagged; and since 1974 all fish have been measured, but only legal-sized fish have been tagged. The number of measured fish has varied from 5 in 1993 to 208 in 2001 and mean total length has varied from 74.5 cm in 1994 to 126.9 cm in 1979 (Table 8). Only in 1974, 1985, and 2001 was the number of green sturgeon measured during tagging great enough to warrant examining the size and age structure - the latter with the constraint that the available age-length key includes only fish age 9 and less and 120 cm and less and with the caveat that green sturgeon are difficult to age.

The size composition of the catch in these 3 years differs substantially (Figure 4) as the mean size increased from 80.5 cm in 1974 to 101.8 cm in 1985 and 109.5 cm in 2001. The differences in size composition of the catch is unlikely to be due to changes in gear, as the changes in mesh sizes that did occur would favor catching smaller fish in recent years. The trammel net was constructed using 20.3-cm stretch measure gill webbing before 1990; since 1990 the net has been variable mesh: 1/4 15.2-cm stretch mesh, 1/4 17.8-cm stretch mesh, and ½ 20.3-cm stretch mesh.

The age composition of the catch was similar in 1985 and 2001, when ages 5-7 dominated in the size and age range for which the age-length key was applicable (Figure 5). Green sturgeon caught during tagging in 1974 were somewhat younger (predominantly ages 4-6) than in the other 2 years. These age distributions provide no strong evidence that green sturgeon produce strong year classes in wet years, as is the case with white sturgeon (Kohlhorst et al. 1991), but the high catches of year classes from the 1990s and the concentration of wet years during that decade suggest such a relationship may exist.

Juvenile Surveys

Red Bluff Diversion Dam catches - Sturgeon at RBDD are sampled by the USFWS using rotary-screw traps intended to catch outmigrant chinook salmon. We do not have access to the original length data, so we cannot provide information on size-frequency distributions. However, the USFWS has summarized some of these data in the form of weekly mean lengths from 1995 to 1998 (February 9, 1999 memorandum from P. Gaines, USFWS to P. Ward, CDFG) and median monthly length for 1995-2000 (Gaines and Martin 2001). Unfortunately, the 1995-

1998 data are described as fork length measurements (Figure 6), whereas the 1995-2000 data show total length (Figure 1). Hence, we do not know how these fish were measured.

Both sets of length date indicate that May-August period when most young sturgeon pass RBDD, the average size ranges from 25 to 50 mm. The weekly data (Figure 6) show that mean size generally increases during this period, suggesting that young sturgeon are rearing and growing above RBDD before moving downstream.

Glenn-Colusa Irrigation District catches - Since 1988, CDFG personnel have recorded the size of young sturgeon collected in a fyke trap (1988-1990) and a rotary-screw trap (1991-2001) at GCID (Appendix C). Most of these fish were between 20 and 50 mm and length frequency distributions were similar in all years (modes between 23 and 38 mm) except 1991, when the mode was centered at 43 mm (Figure 7). Unfortunately, the method for measuring size apparently changed over time, from fork length in 1986-1993 to total length in 1996-2001; the length-measurement method in the intervening years - 1994-1995 - is unclear.

The GCID monthly length data do not show the same general increase in size over the sampling season as seen at RBDD (Table 3, Figure 8). Of the 8 years with sufficient monthly data to look at trends, only 1993 and 1997 offer the suggestion of consistent growth over time. The reason(s) for the difference from the growth pattern at RBDD is unknown, but may be due to sampling fish spawned both above and below RBDD, whereas sampling at RBDD captured only fish spawned above the dam. Perhaps, closure of the dam gates on May 15 results in more protracted spawning below the dam (only early migrant, early spawners make it above the dam) and continued recruitment of the smallest size class of downstream migrant sturgeon throughout the summer. Some late spawning of green sturgeon is suggested by catches of 34-36-mm larvae in October 1997, 1999, and 2000. If data were available, comparisons of length variability between sturgeon caught at RBDD and GCID might indicate whether a wider size range existed at GCID.

A potential problem with length data from rotary-screw traps at both RBDD and GCID is the efficiency for small green sturgeon of gear designed to capture juvenile chinook salmon. Because they sample near the surface, the traps are probably inefficient at capturing a species like green sturgeon that is not surface oriented. In addition, the traps may become less efficient as sturgeon grow and this may explain the slow apparent growth, especially at GCID.

San Francisco Bay Outflow Study - The Bay Study has captured only 61 juvenile sturgeon since it started in 1980 (Table 4). They have ranged in size from 20 to 112 cm TL, but fish from 20 to 60 cm (probably mostly age 1) dominated the catch (Figure 9).

Juvenile sampling - The earliest information on juvenile green sturgeon size distribution in the estuary is from the Delta Fish and Wildlife Protection Study. These results were published in 1966 as CDFG Fish Bulletins 133 and 136. Ganssle (1966) caught 34 juvenile green sturgeon in gill nets and otter trawls in Suisun and San Pablo bays between January 1963 and December 1994. In Suisun Bay, 10 of the green sturgeon were 27-35 cm and five were 40-48 cm. In San Pablo Bay, one fish was 25 cm and the other 18 fish were between 40 and 74 cm. Ganssle does not indicate whether these were fork lengths or total lengths.

Similar sampling in the delta between September 1963 and August 1964 collected 138 juvenile green sturgeon in gill nets and 28 in an otter trawl (Radtke 1966). Green sturgeon caught during this survey ranged from about 20 to 58 cm FL (Figure 10). Most of these fish were probably ages 0 and 1.

The more recent juvenile sturgeon sampling (1988-2001) with gill nets, otter trawl, and baited set-lines to index year class strength of white sturgeon has caught 21 green sturgeon (Table 5). Except for one 169-cm TL adult and a 122-cm fish that was probably immature, all these were juveniles from 32 to 71 cm TL. This sample size is not large enough to draw any inferences about size distribution.

Salvage - Since 1968, 86 green sturgeon have been measured at the State Fish Facilities and 41 have been measured at the Federal Fish Facilities (Figure 11, Appendix D). These small sample sizes for 33 years of salvage records make it impossible to draw any conclusions about annual variations in size of green sturgeon salvaged. As in other juvenile sampling in the estuary, most of these fish appear to be age 0 and 1. Overall, mean fork length of green sturgeon seen at the state facility (30.2 cm) was not significantly different than at the federal facility (32.4) ($t = 1.02$, $p > 0.30$).

Incidental Observations

Green sturgeon have been incidently caught in gill nets and fyke traps used to capture striped bass for tagging during the spring (see Range, Distribution, and Migration). None of the

six green sturgeon caught in fyke traps were measured, but the 20 fish caught in the striped bass gill nets ranged in size from 42 to 108 cm TL; all but three were ≤71 cm (Appendix F).

Klamath River

Information on growth of Klamath River green sturgeon comes from two length-age graphs, one compiled from sturgeon caught in 1979-1982 (Figure 12) (USFWS 1983) and the other from catches in 1990-1993 (Figure 13) (Nakamoto and Kisanuki 1995). All these aged fish came from beach seining in the Klamath River estuary and from harvest monitoring of the tribal gill net fishery in the lower 70 rkm of the river. Lengths of age 0 fish in the 1979-1982 age-length relationship (Figure 12) are a maximum of about 30 cm TL, whereas age 1 fish appear to be between 35 and 45 cm TL. Thus, 30 cm is about the maximum size of a age 0 green sturgeon in the Klamath River.

Adults

From 1980 to 1983, in a sample of 151 mature green sturgeon caught by gill net, seine, and hook and line (snagged) in the Klamath River downstream of Weitchpec (Krkm 69.7), mature males averaged 166.0 cm TL (s = 14.0, n = 88, range 139-207) and females averaged 189.6 cm TL (s = 15.1, n = 63, range 130-228) (Figure 14) (USFWS 1984). Most (90%) males were <187 cm and most females were >171 cm.

Total lengths of green sturgeon harvested by the tribal fisheries on the lower Klamath River changed little between 1980 and 1992, the only years for which data are available (Table 9) (USFWS 1994). These data are not reliable as an indicator of size trends as they represent only catches near the mouth of the river, are only a small sample of all tribal harvest, were caught by different gear in some years, and seem to include some fish from USFWS beach seining in the early years.

Additional information about the size of adult and subadult green sturgeon in the river is available from CDFG seining for salmon and steelhead at Krkm 4 in the estuary from May 17 to August 1, 1977, when 48 green sturgeon from 70 to 210 cm (whether fork or total length is unknown) were captured (Figure 15, Appendix J). Mean length of the adult-sized fish in this

sample was 165.3 cm (s = 15.19, n = 47).

Juveniles

Seining and gill net catches of juvenile green sturgeon by the USFWS (1985) in 1979-1984 from just inside the mouth of the Klamath River (Krkm 0.1) ranged in size from 30 to 130 cm TL (Figure 16). According to available length-age information, these fish were probably between 1 and 15 years old. An increasing size distribution of the catch between 1979 and 1981 led the USFWS (1982) to hypothesize that they were sampling a strong year class of Klamath system origin that was growing over time, implying that these were coastal migrants of local origin that were re-entering the Klamath River estuary after spending time in the ocean.

Beach seine catches of green sturgeon by the CDFG from the upper estuary (Krkm 4 to 5), from August to early October, 1984-1990 were composed mostly of age 0 and 1 fish (Figure 17, Appendix J). These seining sites were probably upstream of the estuary mixing zone, as river velocity varied with the tide, but did not reverse (Hopelain 1988).

Healey (1973), sampling in the Trinity River near Willow Creek (Trkm 40) in 1968 found YOY green sturgeon ranging from 66 to 151 mm TL in July, 91 to 208 mm in August, and 173 to 249 mm in September 1968 (Figure 18). These fish are presumed to be YOY and increased length over time is due to growth. Monthly mean lengths could not be calculated because original data are not available.

The USFWS (1999), fishing rotary-screw traps for salmonids at Big Bar on the Klamath River (Krkm 80) and Willow Creek on the Trinity River (Trkm 40) in 1996 captured YOY green sturgeon from 20 to about 150 mm TL (Figure 19). Catches at Big Bar suggest a prolonged spawning period and some growth above the trap site, whereas catches at Willow Creek suggest only a brief spawning period with considerable growth upstream of the trapping site. The latter is consistent with the interpretation of Healey's (1973) data.

In culture, green sturgeon reached 74 mm 45 days after hatching (Deng 2000). This is consistent with growth curves that indicate that green sturgeon reach about 30 cm by the end of their first year.

Eel River

Aside from the information in Range, Distribution, and Migration, we have no data on size or age structure of green sturgeon in the Eel River.

Other Coastal Rivers and Bays

Among these other areas, size data are available only for green sturgeon tagged in Arcata Bay in 1956 and 1992-1993 (Appendix G). The fish tagged in 1992-1993 were significantly larger (mean = 131.1 cm TL) than those tagged in 1956 (87.0 cm TL) ($t = 11.41$, $p < 0.001$) (Figure 20). We do not know if this is a true increase in size of green sturgeon using Arcata Bay or an artifact of the gear used to capture the fish. We believe both groups of fish were captured incidental to bottom trawling by oyster growers to reduce the number of bat rays in the vicinity of the oyster beds. However, we presently have no information on how the trawls or fishing methods differed between the two collection periods. It is possible that large green sturgeon were more vulnerable to the fishing technique used in 1992-1993 than in 1956.

Habitat Use

Sacramento-San Joaquin System

Spawning

Based on information from catches of sturgeon eggs, larvae, and juveniles in the Sacramento River and data on white sturgeon, it appears that green sturgeon spawn in late spring and early summer from above Hamilton City to above the RBDD, maybe as far upstream as Keswick Dam. Present knowledge about green and white sturgeon egg morphology and coloration, larval green sturgeon behavior, and adult distribution make it likely that eggs and larvae collected in previous CDFG sampling in the Sacramento River above the City of Sacramento have been white sturgeon and that green sturgeon are spawning upstream of the main white sturgeon spawning area. The evidence for this includes:

1. No sturgeon larvae were collected in daytime sampling above Colusa in 1973 (Kohlhorst 1976), even though the nets were fished at Ord Bend, Woodson Bridge, and Bend Bridge. If white sturgeon spawned above Ord Bend, larvae should have been caught at the upstream sampling sites. However, lack of larva catches at upstream locations during the day is consistent with larval green sturgeon behavior, which is distinctly negatively phototaxic. Thus, they would have been unlikely to be caught, even if present.

2. All larvae caught in 1973 were morphologically similar (except for one that was small and darkly pigmented) and none resembled green sturgeon larvae (D. Kohlhorst, CDFG, pers. comm.).

3. Sturgeon eggs collected on artificial substrates between Knights Landing and Princeton (Schaffter 1997) were similar in morphology and coloration and were not consistent with size and coloration of green sturgeon eggs (R. Schaffter, CDFG, pers. comm.).

4. Adult green sturgeon have been observed below RBDD during electrofishing surveys there in April and May 1991, including one dead fish for which identification was certain. However, a few adult white sturgeon, but no green sturgeon were observed the previous year, so identification of fish briefly seen in the water may be unreliable and dependent on the experience of the observer.

5. Two eggs and one larva collected at and above RBDD in early summer 2001 were identified genetically as green sturgeon.

6. The size range of YOY sturgeon (presumably green sturgeon) at both RBDD and GCID suggests that spawning is protracted and extends at least into early summer. The other explanation for small (<40 mm) fish in the river in late summer and fall is that growth is much slower than in the Klamath and Trinity rivers, where YOY fish at that time are more than twice that size.

7. Telemetry indicates that few white sturgeon move above Princeton during spawning migrations (Schaffter 1997), yet many adult sturgeon are seen in the vicinity of RBDD.

Rearing

Based on size and temporal distributions of young green sturgeon, it appears that many of

them rear for the first 1 or 2 months of life in the Sacramento River between Keswick Dam and Hamilton City (Table 3; Figures 1, 6, and 8). Capture of a few 230- to 320-cm fish from July to December in some years (Appendix C) suggests that a few fish may continue to reside in this area for their first year, or move back upstream after rearing elsewhere.

Catches of 1- and 2-year-old green sturgeon on the shoals in the lower San Joaquin River (Radtke 1966), at the fish facilities (Appendix D), and in Suisun and San Pablo bays (Ganssle 1966 and Figure 9) indicates that some fish rear in the estuary for at least 2 years.

The occurrence of larger juvenile and subadult fish in San Pablo Bay and, to a lesser extent, Suisun Bay and the south delta (Figures 4 and 9; Appendices E, F, H, and I) is somewhat puzzling. Apparently these fish have returned to the estuary, possibly temporarily, after spending time in the ocean. The reason for their reappearance in the estuary is unknown (see following section on Sacramento-San Joaquin Estuary feeding).

Feeding

No diet analyses have been done on juvenile green sturgeon rearing in the Sacramento River and little work has been done on feeding of green sturgeon in the Sacramento-San Joaquin estuary. In the early 1960s, Ganssle (1966) found that fish (mostly 1 and 2 years old) in San Pablo and Suisun bays had consumed amphipods, bay and mysid shrimp, clams, annelids, crabs, and fish. During the same period, Radtke (1966) found that age 1 and 2 green sturgeon in the delta fed exclusively on amphipods and mysid shrimp.

It might be expected that the apparent movement of subadult green sturgeon back into the estuary from the ocean might be for the purpose of feeding on the abundance benthic invertebrate fauna. However, attempts to analyze the diet of green sturgeon in the Columbia River estuary in late summer have been unsuccessful because all 50+ stomachs examined were empty (T. Rien, Oregon Department of Wildlife and Fisheries, pers. comm.). In the Sacramento-San Joaquin Estuary, one green sturgeon (97 cm TL) collected during tagging in fall 2001 was examined and contained bay shrimp (*Crangon* sp.) and overbite clams (*Potamocorbula amurensis*) in the gut (N. Kogut, CDFG, pers. comm.). Gut contents of nine more green sturgeon collected during fall 2001 tagging have not yet been examined.

Klamath River System

Spawning

In the Klamath River, breaching and other courtship and spawning behavior of green sturgeon has been repeatedly observed in a pool upstream of Orleans (Krkm 96) (Moyle et al. 1992). Spawning probably takes place in deep, fast water (ibid). The upstream limit of sturgeon migration is Ishi Pishi Falls (Krkm 107), 1 km upstream of the mouth of the Salmon River, where juvenile green sturgeon have been observed (see Range and Distribution). In the Trinity River, Gray's Falls (Trkm 69) is a barrier to upstream migration of sturgeon. Spawning must occur between these barriers and the Big Bar (Krkm 80) and Willow Creek (Trkm 40) trapping sites where larvae and YOY green sturgeon have been captured. It is not known if green sturgeon also spawn below these trapping sites.

Rearing

Coastal migrants - Green sturgeon in the size range of age 3- to 15-year-old fish (Figures 16 and 17) are commonly observed in seine catches in the saline portions of the Klamath River estuary, but are rarely seined in late summer and early fall in the upper, fresher portion of the estuary (Krkm 4-5). Thus, they probably only use the saline portion of the estuary.

Larvae and Juveniles - As YOY green sturgeon have been found both in the Salmon River (see Range and Distribution) and in seine catches between rkm 4 and 5 (Figure 17) (see Size and Age Structure), the entire mainstem Klamath and mainstem Trinity rivers below Gray's and Ishi Pishi falls, as well as an unknown portion of the Salmon River, is juvenile rearing habitat.

Feeding

Little information is available on green sturgeon diet or feeding behavior in the Klamath River system. During 1980, stomachs from nine male and seven female adult sturgeon captured in the Klamath River below Weitchpec were empty (USFWS 1981).

Eel River

There is not enough information available from the Eel River to estimate spawning habitat use other than it must include some area upstream of Fort Seward (rkm 109), where YOY juveniles were captured in 1968, and must extend at least to rkm 160 near where adult sturgeon have been observed.

If green sturgeon in the Eel River behave similar to those in the Klamath River, the entire river to the estuary should be considered juvenile rearing habitat.

No information is available on green sturgeon diet or feeding behavior in the Eel River.

Other Coastal Rivers and Bays

Not much can be said about green sturgeon habitat use in other coastal rivers and bays other than that they occur in some of these areas, such as Arcata Bay (see previous sections). We know of no data on feeding habits of green sturgeon in other coastal areas. It is possible that green sturgeon in Arcata Bay are feeding there, but no gut contents have been collected.

Pacific Ocean

Little information is available on green sturgeon habitat use in the ocean off California. They have been incidently caught in commercial fisheries in nearshore areas in Monterey Bay and near Bodega Head (Table 2), in Tomales Bay (C. Knutson, CDFG, pers. comm.) and in the surf off beaches just south of San Francisco Bay (J. Klinger, Pacifica Tribune, pers. comm.).

Abundance

Sacramento-San Joaquin System

Tagging

Recaptures of tagged white sturgeon in the trammel nets (tagged green sturgeon have never been recaptured in the trammel nets) are recorded and used, in conjunction with the number tagged, to estimate abundance in previous years using the Petersen estimator and in the same year using a multiple-census technique (Ricker 1975). As no independent green sturgeon abundance estimate is possible with no recaptures, their abundance is estimated by multiplying white sturgeon abundance estimates by the ratio of green sturgeon catch to white sturgeon catch (fish ≥102 cm only) during tagging. This assumes that both species are equally vulnerable to being caught in the trammel net and that the movements and temporal distribution in the estuary of fish ≥102 cm of both species is similar. Neither of these assumptions likely is met; green sturgeon size, body shape, and shape of scutes probably affect their vulnerability to the net relative to white sturgeon and the migratory nature of green sturgeon suggests that a lower proportion of the population, especially the spawning population, is in the estuary in the fall than white sturgeon. Nevertheless, this is the only estimate of actual abundance available for green sturgeon in California.

The ratio of green sturgeon to white sturgeon (≥102 cm) in the tagging catches has varied greatly over the years, from 0.002 in 1998 to 0.030 in 2001 (excluding 1994, when no green sturgeon ≥102 cm were caught) (Table 10). This variability probably has as much to do with sampling error in capturing the relatively rare green sturgeon as it does to actual annual changes in relative abundance. This is further evidence that the green sturgeon population estimates should be viewed with caution.

As an aside, and consistent with the expectation that larger green sturgeon are less likely to be found in the estuary in the fall when tagging takes place, the ratio of small (<102 cm) green sturgeon to white sturgeon in tagging catches has generally been greater than for the larger fish (Table 10). Ratios for these younger fish have ranged from 0.011 in 1991 and 1993 to 1.661 in 1974.

Green sturgeon abundance estimates have varied substantially in the Sacramento-San Joaquin Estuary (Table 10). Aside from the high estimated abundance in 2001 of 3,580 fish (based on September and October catches only, to be comparable with estimates in earlier years), the largest estimate was 1,906 in 1979 and the lowest was 198 in 1954. Even without the low

estimate in 1954 and the high estimate in 2001, there is no trend in these data ($F_{1,10} = 1.49$, $p > 0.25$), so they provide no evidence for a green sturgeon population decline in the Sacramento-San Joaquin Estuary. Continued high green sturgeon tagging catch and estimated abundance in 2002 would be consistent with the production of strong year classes in the wet years of the 1990s and, possibly, the benefits of current operation of Red Bluff Diversion Dam.

Juvenile Surveys

Juvenile monitoring surveys designed to index year class strength, as well as incidental catches of larval or juvenile sturgeon in monitoring programs for other species provide information on green sturgeon abundance trends.

Juvenile sturgeon monitoring - Over the years, this has included use of gill nets, otter trawls, and most recently baited set-lines to capture juvenile sturgeon (generally 2-7 years old). These sampling techniques are described in the previous section on the range and distribution of juvenile green sturgeon in the Sacramento-San Joaquin System.

Only 21 green sturgeon have been captured during this sampling (Table 5). Most of the juveniles (16) were captured in gill nets when that gear was fished from 1988 to 1990. An otter trawl caught one juvenile in 1989 and the set-lines caught two juveniles and two older fish in 1998 and 2000. The higher catches in the early years of this survey are probably the result of greater green sturgeon vulnerability to the gill nets used then than to any decrease in abundance after 1990. Thus, the small sample size and change in fishing gear make it impossible to infer trends in juvenile green sturgeon abundance from these data.

San Francisco Bay Outflow Study - This monitoring program has only caught 61 green sturgeon, all juveniles, since its inception in 1980 (Figure 21, Appendix K). Highest catch (10 fish) was in the first year and varied between 0 and 9 thereafter. Annual catches did not exhibit a statistically significant time trend ($F_{1,20} = 2.97$, $p = 0.10$). Monthly catches were too low to ascertain seasonal trends in abundance.

For comparison, the Bay Study has caught 886 white sturgeon, for an overall ratio of 0.069 green sturgeon:1 white sturgeon. This ratio has varied from 0 in 4 years when no green sturgeon were caught to 0.600 in 1994 (Figure 22, Appendix K).

Salvage - State water exports from the south delta began in 1968 and the first green sturgeon were seen at the state fish facilities in March of that year, when 12 fish were estimated to have been salvaged (Appendix L). Estimated salvage per 1000 acre-feet (TAF) of water exported was high in many of the years from the early 1970s to the early 1980s and reached a peak of 3.9 green sturgeon/TAF in 1974 (Figure 23). That was by far the highest estimated salvage per effort at the state fish facilities. From the late 1980s to the present, estimated green sturgeon salvage/TAF has been consistently low, ranging only from 0 to 0.081. The trend in estimated green sturgeon salvage/TAF is not statistically significant ($F_{1,32} = 2.53$, $p > 0.10$), even though highest catches were in the early years of state fish facilities operation.

Federal exports from the delta began in 1951, but no green sturgeon were recorded at the federal fish facility until March 1981, when it was estimated that 75 green sturgeon were salvaged (Appendix L). Federal fish facility estimated green sturgeon salvage/TAF was highest in the mid-1980s and reached a peak of 0.653 in 1983 (Figure 23). Like the state fish facility, estimated salvage at the federal facility was low from the late 1980s to the present; the range was only 0 to 0.096. The decreasing trend in estimated salvage from 1981 to 2001 was statistically significant ($F_{1,19} = 10.61$, $p < 0.01$).

As previously described, salvage monitoring at the state and federal fish facilities in the south delta at times has been plagued by problems with species identification. This is exemplified by the lack of green sturgeon identified at the federal facility until 30 years after export pumping began. An additional source of error is that the salvage estimates commonly are based on expansion of brief counting periods to several hours of operations. Thus, a few fish recorded in a 5-minute count could be expanded to several hundred fish over the several-hour period represented by the 5-minute count. These two factors may account for the sporadic occurrence of green sturgeon in the salvage data and the high variability among months and years (Appendix L). The original salvage data is available from an FTP server found under “Fish Salvage Monitoring” on the CDFG Central Valley Bay-Delta Branch website (www.delta.dfg.ca.gov).

Klamath River System

There are no population estimates available for adult green sturgeon in the Klamath River. Although adult harvest has declined significantly over time (see Harvest section and Table 11), fishing effort has not been constant over time and fishing days have been regulated in response changing salmonid populations in the system. Another factor which may affect harvest efficiency is river flow during the primary spring fishery. These factors have not been analyzed in reports by the USFWS with regard to their impact on sturgeon harvest. We do not have data to assess changes in harvest as an indicator of adult population trends, but this could be a fruitful avenue of investigation.

California Department of Fish and Game beach seine catches per unit effort of juvenile green sturgeon between 1984 and 1990 varied from 0.047 in 1984 to 0.472 in 1987 (Figure 3), suggesting that green sturgeon production in the Klamath River can vary annually by at least an order of magnitude. Lengths of these fish are described in Size and Age Structure.

Eel River

The low number of adult green sturgeon observed in the Eel River (see Range and Distribution) suggests that adult abundance is low and that adults may not enter the river every year. There has been no known sampling for small fish within the river upstream of the estuary since 1970.

Other Coastal Rivers and Bays

We know of no estimates or indices of green sturgeon abundance in other coastal rivers and bays in California or any information about green sturgeon population trends in these areas. Green sturgeon are at least intermittently common in Arcata Bay, as evidenced by the capture in bottom trawls of 49 fish in only 2 days in 1956 and 72 fish in 7 days in 1992 (Appendix G). Records of green sturgeon in other coastal areas are so infrequent that they suggest that they are rare in most other areas.

Harvest

Sacramento-San Joaquin System

Tag returns by fishers during the first year after tagging are used to estimate annual harvest rate. Since 1967, all sturgeon tags have offered a reward to fishers returning them. This reward has increased over time, from $5 initially to up to $100 at present, so it is likely that most recovered tagged green sturgeon are reported to us. This becomes even more likely when one considers the "curiosity factor" that results when a fisher encounters an unusual event, such as the catch of a tagged green sturgeon.

Because relatively few green sturgeon are tagged and even fewer are reported recaptured, estimated harvest rate for most tagging years is zero (Table 12). The exceptions to this are 1948, 1979, 1984, and 1985, when 1, 2, 1, and 1 tags were reported recaptured during the first year after tagging and estimated harvest rates for each of these years were 0.028, 0.077, 0.042, and 0.053. Combining all years of tagging (except 2001, for which first-year returns are not complete), the estimated "average" harvest rate is 0.022 and the 95% confidence interval (assuming that tag return data follow the Poisson distribution - a rare and random event) is 0.009-0.048. These harvest rates are all similar or lower than rates considered to be adequate for maintaining the white sturgeon in the estuary (Kohlhorst et al. 1991).

The actual number of green sturgeon harvested from the Sacramento-San Joaquin population is more difficult to determine because it is likely that many of the fish using or spawning in the system are not available for tagging in the fall; they are in the ocean. Multiplying annual green sturgeon population estimates by the harvest rates yields minimum harvest numbers of 147, 46, and 45 for 1979, 1984, and 1985 (Table 12). No estimate can be made for 1948 because no population estimate is available that year.

Klamath River System

Numerical harvest estimates from 1980 to 1999 have been compiled by the USFWS for

tribal catches on the Klamath River below Weitchpec and the lower 26 km of the Trinity River. These statistics are included as Appendix 2 of the listing petition and reproduced here as Table 11. Partial comparison with the source material (USFWS 1981, 1982, 1983, 1988, 1989, 1992, 1994) indicates that the information in Table 11 is generally accurate, with one exception: all fish listed in the "poached" column have also been included in the Yurok harvest column (USFWS 1981, 1982, 1983). This hook and line (snag) fishery on tribal land at Coon Creek was included in Yurok statistics even though "many (of the fish) were caught by non-Indians" (USFWS 1981:86). There have been other unexplained revisions and corrections of Klamath harvest data during the 1980s, but other changes are minor (USFWS 1994). Estimated harvest in 1980 and 1981 was substantially higher than in other years, but even without those years, the decreasing trend in harvest is statistically significant ($F_{1,16} = 6.18$, $p < 0.05$). These data do not account for effort, so trend in catch per effort is unknown and may be different than for the data that is uncorrected for effort.

Legal sport catches of green sturgeon were observed at Bluff Creek on the Klamath River (Krkm 78) before the sport fishery was closed in 1994, but the extent of this fishery and catch is unknown (USFWS 1982).

Eel River

No estimates of harvest or harvest rate are available from the Eel River. Most of the Eel River system is in Humboldt County and thus is closed to harvest of sturgeon, so there is no legal harvest at present.

Other Coastal Rivers and Bays

No estimates of harvest or harvest rate are available for other coastal rivers or bays. However, some catch of green sturgeon does occur in these areas, as evidenced by the report of two green sturgeon captured by halibut gear in Tomales Bay in August 1993 (Knutson, CDFG, pers. comm.), over 20 fish (including several that were legal sized) in the surf off Pacifica on one

day in May 1995 (J. Klinger, Pacifica Tribune, pers. comm.) and trawl catches in Arcata Bay (Appendix G). Commercial catches in the ocean and bays may result is some mortality even though green sturgeon are not the target of these fishing efforts and must be released.

Habitat Impacts

Sacramento-San Joaquin System

Major historical changes that likely have negatively impacted green sturgeon have occurred in the Sacramento-San Joaquin system, including construction of dams on almost all rivers, filling of the bays, altered hydrology, diversions from the rivers, and water exports from the delta. These and other historical habitat alterations are adequately covered in the listing petition and will not be further discussed here. Instead, we will deal with future activities that have the potential to impact green sturgeon habitat.

Additional Upstream Water Development

As part of the CALFED process to provide additional and more reliable water supplies while also improving conditions for fish and wildlife in the estuary and its tributaries, increased water storage in the Sacramento River basin has been proposed. This could take the form of raising Shasta Dam to impound more water or to store water in a pumped offstream storage reservoir(s) on the west side of the valley. Both of these actions have the potential to detrimentally affect green sturgeon habitat by altering the hydrology of the river above Hamilton City. Specifically, flows could be reduced downstream of Keswick or below the intake for the pumped storage during part of the period of upstream migration of adults. Flow may be a prime cue for upstream migration and spawning (Kohlhorst et al. 1991). Enlarged Shasta may also offer benefits to green sturgeon through higher flows and cooler temperatures during the summer incubation and rearing period. The extent of detriment or benefit will obviously depend on the manner and timing of storage and release of additional water.

Red Bluff Diversion Dam

The operation of RBDD may be modified to better assist passage of adult salmon upstream and juvenile salmon downstream, with consideration also given to sturgeon passage. Essentially, the alternatives being considered are: 1) gates open from September 1 to June 30 (10 months), 2) gates open year-round (12 months), 3) continue current operation of gates open from September 15 to May 15 (8 months). Additionally, improvements to the fish ladders are being considered that may result in upstream passage of sturgeon. All of these alternatives benefit green sturgeon by providing better access to spawning habitat above the dam, even continuation of present operations, which has been shown to result in substantial spawning upstream of the dam. Increasing the period when the dam gates are raised will reduce an impediment to downstream movement of juveniles. Improvements to the fish ladders may also be a benefit if they can be designed to emulate the north ladder on Bonneville Dam on the Columbia River, which passes sturgeon successfully.

Glenn-Colusa Irrigation District

To improve the efficiency of the GCID diversion by providing higher water levels in the intake channel, a weir across the Sacramento River just downstream of the intake channel has been proposed. If this weir is constructed and is in place during periods of green sturgeon migration, it will likely impede upstream movement of adults and may increase downstream passage time for juveniles. If it concentrates predators as happens at RBDD when the gates are closed, it could also result in increased mortality of juvenile sturgeon.

Water Diversions

Aside from the proposed pumped storage reservoir(s) on the west side of the Sacramento Valley, no additional diversions from the Sacramento River above Sacramento are proposed in the near future. However, numerous diversions exist there already and most small diversions are unscreened. Many of the large diversions are now screened and the present emphasis is on screening smaller diversions. The intent of all this screening is to protect juvenile salmonids. Although loss of larval and juvenile sturgeon in these agricultural diversions has not been

documented, it is likely that losses occur, especially as most diversion intakes are near the bottom and sturgeon larvae are demersal. Present screen technology is probably not as effective for sturgeon as for salmonids. Information on white sturgeon behavior in relation to fish screens is available from studies done at UCD and at experimental facilities at Hood in the late 1970s and early 1980s.

Water Temperature

Impacts of possible changes in water temperature as the result of increased water storage in the Sacramento River basin are discussed earlier.

Water temperature that may be inadequate for spawning and egg incubation occurs in the Feather River in many years as the result of release of warmed water from Thermalito Afterbay. This may be one reason neither green nor white sturgeon are found in the river in low-flow years. It is not expected that water temperatures will become more unfavorable in the near future.

Water Exports from the Delta

We have already described the fact that varying numbers of green sturgeon are salvaged at the state and federal fish facilities in the south delta and that subadult green sturgeon have been found in seining surveys in Clifton Court Forebay. As export rates and through-delta movement of water increases in the future, the number of green sturgeon salvaged may increase. However, for white sturgeon, although year-class strength is related to freshwater flows in late winter and spring, it is not related to the volume of water exported from the delta.

A proposal to construct another diversion point on the Sacramento River near Hood to transport water into Snodgrass Slough and ultimately to the pumping plants has the potential for greater negative impact on green sturgeon than just increases in exports without physical changes in the delta's "plumbing." This screened diversion might entrain additional juvenile green sturgeon (beyond the number that now enter the Delta Cross Channel and Georgiana Slough) if it is not efficient for sturgeon.

A more significant impact of this additional screened diversion point is the potential for attracting upstream migrant adults to the downstream side of the screen through Snodgrass Slough

and the need to provide passage for them through or over the screen. The technology for doing this may not exist.

Bay Filling

Filling of San Francisco Bay has historically reduced foraging areas for sturgeon, but this activity has been curtailed in recent years. However, plans to add runway capacity to San Francisco International Airport will result in filling several square kilometers of the bay. This is a contentious issue and may not occur, but if it does, additional sturgeon foraging habitat will be lost without assurance that mitigation will be adequate.

Exotic Species Introductions

Introduction of exotic species is an ongoing problem in the estuary. The most likely impact on green sturgeon of these introductions is through changes in trophic interactions. Many of the recent introductions of invertebrates have greatly affected the benthic fauna in the delta and bays. The overbite clam, first observed in the estuary in 1988, is now the most common food of white sturgeon and was found in the only green sturgeon so far examined among nine fish collected in fall 2001. It appears to have replaced other clams in the diet of white sturgeon.

The recent introduction of the Chinese mitten crab (*Eriocheir sinensis*) may have added a new prey item for green sturgeon, or, perhaps, another competitor. So far, these have not been observed in the diet of either species of sturgeon. However, mitten crabs have had a major impact on the sturgeon fishery, as they are voracious bait stealers from late summer through winter in brackish areas. This has necessitated changes in fishing locations, techniques, and bait - all of which may have made sturgeon anglers less efficient.

In 1963-1964, native mysid shrimp (*Neomysis mercedis*) and amphipods (*Corophium* spp.) were the primary food of green sturgeon in the estuary (Ganssle 1966, Radtke 1966). This mysid is now much less abundant than in the 1960 and has been largely replaced in part of its range by the introduced *Acanthomysis bowmani*. Another isopod, *Gammarus* sp. was added to the delta's benthic fauna recently and a native planktonic copepod (*Eurytemora affinis*) has given way to several introduced species, including *Sinocalanus doerri* and *Pseudodiaptomous forbesi*.

Toxicants

Even with recent improvements in water quality in the Sacramento-San Joaquin system, the influence of toxicants, especially their chronic effects on survival and reproduction of aquatic biota, continue to be of concern. No specific information is available on contaminant loads or impacts in green sturgeon. However, white sturgeon in the past have contained high PCB loads (Kohlhorst 1980), although more recent data showing much lower contamination suggest these earlier results may have been erroneous (D. Kohlhorst, CDFG, pers. comm.; unpublished CDFG data). White sturgeon in the estuary do accumulate selenium, but tissue concentrations have varied among years without trend and do not seem to be related to fish size (White et al. 1989). The difference in distribution of green and white sturgeon (ocean migrants vs. estuarine inhabitants) probably makes green sturgeon less vulnerable than white sturgeon to bioaccumulation of contaminants found in the estuary.

Klamath River System

Two important habitat characteristics critical to successful green sturgeon spawning and rearing in the Klamath River system are maintenance of suitable spawning habitats and maintenance of suitable water temperature, at least during egg incubation and larva rearing.

Deng (2000) suggested that green sturgeon eggs, because of there relative lack of adhesiveness, depend on being trapped in crevices in bedrock or under gravel. Larvae younger than 6 days posthatch show very limited mobility and older larvae exhibit strong negative phototaxis, behavior which would allow them to develop within relatively short, high gradient streams (ibid). Thus, the introduction of finer substrate material, especially covering bedrock, cobble, or coarse gravel, is probably detrimental to green sturgeon.

Cool water temperatures are also probably important to green sturgeon egg and larva development. Optimal temperatures for egg survival and development of other species of sturgeon is about 14 to 17^{o}C and egg and larva survival decreasing rapidly at higher temperatures (Wang et al. 1985).

Past logging practices have contributed to sedimentation in the Klamath River system. The loss of sturgeon spawning habitat in the South Fork Trinity River is largely the result of road building and clear-cutting. Logging practices are much better than in the past, but any additional sedimentation in remaining spawning habitat in the Klamath system is likely to be detrimental to green sturgeon spawning success.

Both the Klamath and Trinity Rivers have upstream demands on water that could effect temperatures in the lower reaches where green sturgeon spawn and rear and the temperature effect of present and future water development on these rivers needs to be considered.

Eel River

The Eel River has probably been more affected by erosion from past logging and other land use practices than the Klamath-Trinity system. Also, water temperatures may be more of a problem in this drainage because of the more southern geographical location and lower elevation of the Eel River watershed.

Other Coastal Rivers and Bays

Due to improvements in treatment of industrial and municipal waste and restriction on dumping such waste into bays, conditions for ocean migrant juveniles and adults have probably improved in most coastal bays in recent years. However, logging, road building, and agricultural activities, among others, in watersheds that historically contained green sturgeon may inhibit recolonization of these areas.

Conservation Actions

Sacramento-San Joaquin System

Angling Regulations

Both species of sturgeon are now protected by sport angling regulations (no commercial harvest is permitted) that allow the year-round take of one fish per day between 117 and 183 cm TL. In addition, a closure of central San Francisco Bay during the herring spawning season (January 1-March 15) protects sturgeon when they are concentrated feeding on herring eggs. As female green sturgeon may not mature until they are about 150 cm, they are vulnerable to the sport fishery for many years. Their vulnerability is decreased by the fact that they spend most of this period in the ocean where they are infrequently caught.

No changes in angling regulations are contemplated at this time. Because legal-sized green sturgeon are easily distinguished from white sturgeon and are a very minor component of the sport fishery, closure of the estuary and its tributaries to green sturgeon fishing would be effective and cause little impact to the fishery.

Enforcement Activities

Active enforcement of sturgeon angling regulations is a priority at times and in areas where sturgeon are concentrated and vulnerable to the fishery, such as the delta to San Pablo Bay area in late winter and the upper Sacramento River during the spawning migration. The trophy status of white sturgeon and the consequent incentive for retaining oversize (>183 cm) fish is another impetus for active enforcement of sturgeon angling regulations.

No increase in CDFG enforcement activity for sturgeon is anticipated at this time.

Current and Planned Operation of Red Bluff Diversion Dam

See the above section on Habitat Impacts.

Anadromous Fish Restoration Plan (AFRP)

This component of the Central Valley Project Improvement Act (CVPIA) implements the CVPIA goal to double natural production of anadromous fishes (including sturgeon) in the Central Valley by this year (2002). Tools available include enhancing stream flows, relocating and screening diversions, and using up to 800,000 acre-feet of Central Valley Project yield for fish and wildlife restoration. We are not aware of any AFRP actions specifically designed to

benefit green sturgeon, but they may benefit from actions taken to increase production of other species.

CALFED Bay-Delta Program

The CALFED Program seeks to recover the green sturgeon by restoring its population distribution and abundance to historical levels. The CALFED Ecosystem Restoration Program Plan (ERPP) addresses some of the major factors limiting the green sturgeon population, including adequate stream flows for attracting adults to spawning areas in rivers, transporting young to nursery areas, illegal and legal harvest, and entrainment into water diversions. The ERPP calls for actions that restore ecological processes, restore spawning habitat, improve the aquatic food web, reduce stressors, and improve water quality. For instance, the ERPP could benefit green sturgeon by providing inflow to the delta for the Sacramento River greater than 25,000 cfs during the March to May spawning period in at least 2 of every 5 years (an action based on production-flow relations for white sturgeon) and improving spring flows in major tributaries to the Sacramento River. Other beneficial actions include restoring natural meander belts; adding gravel substrate in upstream spawning areas; and restoring tidal perennial aquatic habitat, fresh emergent wetland, and delta sloughs. The ERPP also calls for eliminating migration barriers such as diversion dams, reducing stranding in the Yolo Bypass, and improving water quality to reduce concentrations of toxic substances in prey that can concentrate in sturgeon and adversely effect green sturgeon health and reproduction. A new state-of-the-art fish screen and fish salvage facility for the State Water Project will also help reduce export impacts on green sturgeon. Finally, the ERPP calls for research to fill in knowledge gaps for green sturgeon with respect to habitat requirements, distribution of spawning habitat, flow requirements, and factors limiting abundance.

Klamath River System

Angling Regulations

From 1954 to 1977, the Klamath River was regulated by statewide sturgeon regulations which allowed the year-round take of one sturgeon per day with a minimum size of 102 cm TL;

snagging was prohibited. From 1978 to 1993, a further restriction on harvest was imposed in the form of a spawning closure that prohibited the take of sturgeon in the Klamath River from the mouth of the Trinity River upstream to and including Ishi Pishi Falls from April 1 through July 15. In 1990, a maximum size limit of 183 cm was instituted and the minimum size limit was increased in 5-cm annual increments until it reached 117 cm. Since 1993, all sturgeon fishing has been prohibited in Del Norte, Humboldt, Siskiyou and Trinity counties. This closure covers all waters used by sturgeon in the Klamath-Trinity system.

Enforcement Activities

Local CDFG wardens monitor fisheries within their districts on the Klamath and Trinity rivers, and special enforcement activities have taken place where problems occur.

Eel River

Angling Regulations

Sturgeon on portions of the Eel River where adult sturgeon have recently been observed by CDFG biologists and at all locations where juvenile sturgeon have been documented (Puckett 1976) have been protected since 1993 by the same sturgeon fishery closure in effect for the Klamath River. This closure covers the Eel River from the mouth to rkm 153 and includes all waters in the South Fork Eel River downstream of Benbow Dam.

Enforcement Activities

CDFG enforcement personnel feel that enforcement problems on the Eel River are less than in the past because of reduced population in remote areas because of a decline in logging within the watershed (S. Downie, CDFG, pers. comm.).

Other Coastal Rivers and Bays

Sturgeon fishing in rivers and bays in Del Norte and Humboldt counties has been prohibited

since 1993. These closed waters include the Smith River, Humboldt and Arcata bays, and all tidal sections of rivers, creeks, and bays. From Mendocino County south, green sturgeon fisheries are subject to the general sturgeon angling regulations: a year-round season with one fish per day between 117 and 183 cm TL.

CONCLUSIONS

In this section we present our conclusions about the status of green sturgeon in California, based on available information, and generally organized according to some concerns expressed in the listing petition.

Green sturgeon have suffered a general (or recent) decline in abundance - Measures available to the CDFG for assessing green sturgeon abundance, or abundance trends, are all deficient in some way: they are indirect (population estimates from tagging), rely on small numbers of fish (San Francisco Bay Outflow Study catches), are of short duration (RBDD catches and CDFG seine catches in the Klamath River estuary, rely on unreliable species identification (state and federal fish facility salvage), or lack data to correct for temporal changes in effort (tribal harvest in the Klamath River system). Only two measures exhibit a significant decreasing trend over their period of record and these are probably the least reliable abundance indicators (salvage records and tribal harvest). Other abundance measures exhibit no time trend.

In this regard, the statement that the green sturgeon has suffered an "88% decline in most of [its] range" (Musick et al. 2000:10) cited by the listing petition, and the December 14, 2001 Federal Register notice of petition finding, cannot be substantiated with any data. Musick et al. in turn cite Houston (1988) who actually states that "there is no evidence for a general population decline" (p. 288). An inquiry from R. Schaffter of the CDFG to Dr. Musick resulted in an E-mail response to Mr. Schaffter from Dan Ha on February 13, 2002, who indicated that he had written the sections on sturgeon in Musick et al. (2000) and that his response had been "read and approved" by Dr. Musick. His response is as follows:

> "We would like to apologize for the missing citations, and incorrect figure in the

section on green sturgeon (which is also incorrect in the section on white). It should read, '...98% decline in most of its range (Cech 1992, Hart 1973),...

The misunderstanding comes from the need for compressing a great deal of information into a short paper. The original draft of this section read as follows, 'The abundance of all west coast sturgeons, including green, suffered approximately an 88% decline in California, as inferred from commercial catch rates (Cech 1992). Similar declines occurred in other areas (Hart 1973). Early commercial fisheries records do not distinguish between white and green sturgeons, and hence, exact figures for each are unavailable.' NMFS did not distinguish between white and green sturgeons in its records until 1980.

We do not debate that this is a tenuous estimation, however, it is the best approximation we have. Note that this is not the only risk criterion we found applicable to green sturgeon; it also has the risk factors of rarity and specialized habitat requirements. Furthermore, we acknowledge in the article that data are needed for precise determination of status."

Hart (1973) presents no information concerning green sturgeon abundance trends, although he does show commercial harvest figure for white sturgeon in the Fraser River. Cech (1992) presents sturgeon party boat catch figures during a period of declining party boat fishing effort in his article on white sturgeon.

Green sturgeon distribution has been restricted - Restrictions in green sturgeon distribution mostly would occur as the result of loss of spawning habitat, either through dam building, sedimentation, or degradation of water quality (including temperature changes). There is no evidence that their marine habitat has been diminished, although historically, potential foraging area in San Francisco Bay has been reduced by bay fill.

Historical accounts, and what little data are available, support the loss of spawning habitat in the South Fork Trinity River and the Eel River system due to anthropomorphic changes and natural events that, in combination, increased sedimentation. However, observations in the 1990s suggest that a small spawning population of green sturgeon still uses the Eel River.

Loss of habitat in the Klamath River and in Central Valley streams is more problematic.

Both the Klamath and Trinity Rivers have barriers to upstream migration of sturgeon that are well below existing reservoirs, so the dams that created those reservoirs are unlikely to have blocked access to historical spawning areas.

In the Central Valley, the most likely loss of spawning habitat is in the Feather River, as Oroville Dam blocks access to potential spawning habitat and Thermalito Afterbay warm water releases may increase temperatures to levels that are undesirable for spawning and incubation. Nevertheless, anecdotal evidence suggests that adult green sturgeon are still found in the Feather River in high flow years, presumably as they take advantage of intermittent opportunities for successful spawning.

We know of no evidence that green sturgeon historically spawned in the San Joaquin River. Based on movement of other fishes in the delta, young green sturgeon found in the lower San Joaquin River could easily, and most likely, have come from the known spawning population in the Sacramento River. No sturgeon of either species appear to have trapped behind Friant Dam on the San Joaquin River when it was constructed in the 1940s (R. Kelly, CDFG, pers. comm.)

Present spawning of green sturgeon in the remaining accessible areas of the Sacramento River upstream of Hamilton City, and their apparent ready use of additional spawning habitat made available by the re-operation of RBDD in the early 1990s, suggest that they historically spawned above Shasta Dam. It is, therefore, surprising that only white sturgeon were ever observed in Lake Shasta (Fisk 1963).

Exploitation presently threatens green sturgeon - The two areas of greatest green sturgeon harvest are the Klamath River and estuaries and bays in Oregon and Washington. While numerical harvest estimates by the tribal fisheries in the Klamath River are available, we have no information concerning effort, so trends in catch per effort cannot adequately be explored. As the important statistic is harvest rate (fraction of the population harvested annually), not number of fish caught, either estimates of abundance or a tagging program are needed to adequately evaluate exploitation of the Klamath River stock.

Limited information of that sort is available for green sturgeon in the Sacramento-San Joaquin system. Annual harvest rate estimates from the tagging program there ranged from 2.8 to

7.7% and almost all of that harvest was in Oregon and Washington. Because few green sturgeon are tagged in most years, tag recaptures by fishers are rare. Combining all tag returns and all releases yields an "average" harvest rate of 2.2%. The impact of these low harvest rates on the population is unknown. While it is generally felt that harvest rates >10% will lead to long-term population declines in white sturgeon (Kohlhorst et al. 1991), even lower rates may be excessive for a rarer species like green sturgeon.

Adequacy of present conservation measures - In California, state regulations allow only sport fishing for green sturgeon. Besides restrictive size and creel limits, sturgeon angling is prohibited in all areas of the Klamath River system inhabited by green sturgeon and in most of the Eel River. The only legal harvest in these north coast rivers is by the tribal fisheries in the Klamath system. The extent of illegal harvest is unknown.

In the Sacramento-San Joaquin system, although some green sturgeon are harvested, angling regulations are almost irrelevant because almost all harvest of fish tagged there takes place in other states. Harvest rates for these fish were estimated in years before the present 117-183-cm slot limit was instituted, so within the estuary and its tributaries, green sturgeon are afforded even more protection than reflected in those estimates. The increase in the minimum size limit from 102 to 117 cm is probably more beneficial than the maximum 183-cm limit, as it protects many subadult green sturgeon that sometimes enter the estuary.

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Table 1. Green sturgeon tagging summary for the Sacramento-San Joaquin Estuary, 1948-2001.

Year	Number tagged
1948	36
1949	6
1954	26
1967	25
1968	28
1974	7
1979	26
1984	24
1985	19
1987	6
1990	12
1991	5
1993	2
1997	8
2001	45
Grand Total	275

Table 2. Recovery information for green sturgeon tagged in the Sacramento-San Joaquin Estuary from 1948 to 1987.

Date tagged	Total length (cm)	Date recaptured	Location recaptured	Recapture method	Days at large
22-Sep-48	65	7-Apr-49	Monterey Bay, CA	Commercial	197
27-Sep-54	130	28-Aug-58	Columbia River, WA	Commercial gill net	1431
29-Sep-54	104	4-Dec-55	Columbia River, OR	Commercial otter trawl	431
30-Sep-54	117	1-Sep-57	Winchester Bay, OR	Commercial gill net	1067
11-Oct-67	127	25-Jul-69	Grays Harbor, WA	Commercial	653
15-Oct-67[a]	114-127[a]	20-Sep-68	Columbia River, OR	Commercial	341
15-Oct-67[a]	114-127[a]	17-Aug-70	Columbia River, OR	Commercial	1037
15-Oct-67[a]	114-127[a]	1-Jan-71	San Pablo Bay, CA	Sport	1174
27-Oct-67	117	23-Dec-67	Monterey Bay, CA	Commercial halibut trawl	57
14-Sep-79	106	2-Sep-80	Westport, WA	Tag found in gill net	354
11-Oct-79	145	14-Nov-79	Bodega Head, CA	Unknown	34
19-Sep-84	116	11-Dec-84	San Pablo Bay, CA	Sport (CPFV)	83
10-Sep-84	108	9-Jul-88	Grays Harbor, WA	Commercial gill net	1398
11-Sep-84	108	8-Sep-87	Columbia River, OR	Commercial gill net	1092
2-Oct-84	129	1-Aug-86	Columbia River, WA	Commercial gill net	668
9-Sep-85	188	30-Jul-86	Columbia River, OR	Commercial gill net	324
11-Sep-85	124	15-Sep-85	San Pablo Bay, CA?	Unknown	4
23-Oct-87	106	10-Oct-90	Near Astoria, OR	Commercial	1083

[a] Exact date of tagging unknown; length also unknown, but within range shown.

Table 3. Monthly mean length (fork length in 1986-1993, total length in 1996-2001, measurement method unknown in 1994-1995), standard deviation, and range of larval and post-larval sturgeon captured at the Glenn-Colusa Irrigation District diversion in a fyke trap from 1986 to 1990 and rotary-screw trap from 1991 to 2001. Only fish <100 mm are included; number caught and the range of lengths are the only data available for 1994 and 1995; no sampling was conducted in 1998.

	May				June				July			
Year	Mean	S.D.	Range	N	Mean	S.D.	Range	N	Mean	S.D.	Range	N
1986									38.5	2.1	37-40	2
1987												
1988					30.0	7.1	19-38	6	37.1	10.7	26-38	9
1989									47.0	-	47	1
1990					24.7	0.6	24-25	9	27.8	3.6	23-33	3
1991					38.2	8.3	24-61	23	37.6	6.6	25-67	110
1992	34.5	4.3	30-51	36	30.4	5.9	26-80	110	31.4	2.4	27-35	163
1993	30.3	4.5	21-43	76	32.3	3.6	27-39	11	32.8	4.4	26-76	504
1994							26-58	12			26-36	26
1995							28-35	20			22-79	205
1996	34.0	6.9	23-51	41	41.8	22.0	26-98	9	36.1	8.7	20-70	152
1997	31.1	2.2	26-36	28	33.1	4.9	23-53	125	35.3	4.6	26-46	53
1998	-	-	-	-	-	-	-	-	-	-	-	-
1999					35.9	4.2	30-44	23	36.6	8.1	25-85	170
2000	29.0	0.0	29	1	36.6	11.9	28-71	12	36.9	7.6	24-57	17
2001	39.0	6.1	31-46	3	42.2	16.6	27-87	12	37.1	5.5	24-46	16

	August				September				October			
Year	Mean	S.D.	Range	N	Mean	S.D.	Range	N	Mean	S.D.	Range	N
1986	50.0	0.0	50	2								
1987												
1988												
1989												
1990												
1991	37.6	4.3	29-41	6								
1992	31.8	3.3	28-37	11								
1993	35.5	5.7	29-62	89	40.0	-	40	1				
1994												
1995			29-52	79			57-75	3				
1996	34.9	8.5	26-92	112								
1997	37.0	4.7	29-46	20	37.5	0.7	37-38	2	35.0	0.8	34-36	4
1998	-	-	-	-	-	-	-	-	-	-	-	-
1999	35.0	11.2	30-70	43	36.0	0.0	36-36	2	34.0	-	34	1
2000	35.0	4.2	32-38	2					32.0	-	32	1
2001	28.0	0.0	28	1								

Table 4. Month and location of juvenile green sturgeon catches by San Francisco Bay Outflow Study otter and midwater trawl sampling from 1980 to 2001.

	Location					
Month	South San Francisco Bay	Central San Francisco Bay	San Pablo Bay	Suisun Bay	Delta	Total
1				1		1
2			1	1	2	4
3				1	2	3
4	2	1	3			6
5			1	2	3	6
6		2	1	6	1	10
7		1	2	3		6
8		1		5	1	7
9	1		2	1	3	7
10		1		4	1	6
11				4		4
12					1	1
Total	3	6	10	21	14	61

Table 5. Green sturgeon catches during juvenile sturgeon sampling designed to index year-class strength of white sturgeon in the Sacramento-San Joaquin Estuary, 1988-2001.

Year	Month	Day	Location	Method	Sampling duration (hrs)	Total Length
1988	8	25	Honker Bay - Simmons Pt.	Set gill net	24:00	52
1988	9	14	Grizzly Bay - Dolphin	Set gill net	24:50	54
1988	9	20	Southhampton Bay	Set gill net	21:25	55
1988	9	21	San Pablo Bay - Petaluma Channel	Set gill net	19:55	59
1989	8	28	Suisun Bay - Lower Reserve Fleet	Set gill net	25:45	53
1989	8	29	San Pablo Bay - Rockwall	Set gill net	22:00	50
1989	8	29	Carquinez Strait - Ozol	Set gill net	24:20	48
1989	8	29	Carquinez Strait - Ozol	Set gill net	24:20	54
1989	10	23	Sacramento R. - Rio Vista	Otter trawl	0:10	32
1989	4	25	Chipps Is.	Set gill net	20:45	37
1989	4	25	Sacramento R. - Chain Is.	Set gill net	21:40	34
1989	5	25	San Pablo Bay - Rockwall	Set gill net	21:30	71
1989	7	24	Sherman Lake	Set gill net	19:25	54
1989	7	27	San Pablo Bay - Rockwall	Set gill net	20:00	49
1989	7	27	Suisun Bay - Lower Reserve Fleet	Set gill net	19:00	66
1990	7	2	Sacramento R. - Decker Is.	Drift gill net	0:40	46
1990	7	2	Sacramento R. - Decker Is.	Drift gill net	0:40	47
1998	8	19	San Pablo Bay - Rockwall	Set-line	20:00	57
2000	7	20	Suisun Bay - Garnet Pt.	Set-line	20:00	57
2000	7	24	Broad Sl	Set-line	20:00	169
2000	8	31	San Pablo Bay - Rockwall	Set-line	20:00	122

Table 6. Juvenile green sturgeon catches in the mainstem Eel River from 1967 to 1970, expressed as fish per sample day. NS = not sampled.

		Green sturgeon per day					
Site	Year	May	Jun	Jul	Aug	Sep	Oct-Nov
Rio Dell, rkm 32	1967	NS	NS	NS	0.1	NS	0
Holmes, rkm 58	1967	NS	NS	NS	0.6	0	0
McCann, rkm 76	1967	NS	NS	NS	4.4	NS	NS
McCann	1968	0	0	0.4	0	0	0
McCann	1969	0	0	12.3	0	0	0
McCann	1970	0	1.0	0[a]	0	0	0
Eel Rock, rkm 88	1967	NS	NS	NS	3.7	0	NS
Ft. Seward, rkm 109	1968	27.6	0	0	0	0	5

[a] Only 1 sample day during July 1970

Table 7. Age-length key from green sturgeon collected in the Sacramento-San Joaquin Estuary from 1965 to 1976.

Length					Age					
group	1	2	3	4	5	6	7	8	9	Total
35-39	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
40-44	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
45-49										0.000
50-54	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
55-59	0.000	0.444	0.333	0.222	0.000	0.000	0.000	0.000	0.000	1.000
60-64	0.000	0.176	0.471	0.353	0.000	0.000	0.000	0.000	0.000	1.000
65-69	0.000	0.158	0.211	0.421	0.105	0.053	0.000	0.053	0.000	1.000
70-74	0.000	0.000	0.118	0.353	0.353	0.118	0.059	0.000	0.000	1.000
75-79	0.000	0.000	0.033	0.333	0.467	0.167	0.000	0.000	0.000	1.000
80-84	0.000	0.000	0.053	0.105	0.421	0.263	0.105	0.053	0.000	1.000
85-89	0.000	0.000	0.000	0.077	0.385	0.538	0.000	0.000	0.000	1.000
90-94	0.000	0.000	0.000	0.000	0.000	0.400	0.400	0.200	0.000	1.000
95-99	0.000	0.000	0.000	0.000	0.000	0.667	0.333	0.000	0.000	1.000
100-104	0.000	0.000	0.000	0.200	0.600	0.000	0.000	0.000	0.200	1.000
105-109	0.000	0.000	0.000	0.000	0.000	0.000	0.667	0.333	0.000	1.000
110-114	0.000	0.000	0.000	0.000	0.250	0.000	0.500	0.000	0.250	1.000
115-119	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000

Table 8. Size statistics for green sturgeon captured during tagging in the Sacramento-San Joaquin Estuary from 1948 to 2001.

Year	Total measured	Mean total length (cm)	Standard deviation (cm)	Coefficient of variation
1948	36	89.2	16.98	19.0%
1949	6	114.5	36.72	32.1%
1954	25	106.3	13.88	13.1%
1967	25	115.7	16.49	14.3%
1968	28	124.2	25.48	20.5%
1974	103	80.5	19.40	24.1%
1979	26	126.9	21.29	16.8%
1984	31	122.8	32.13	26.2%
1985	66	101.8	28.31	27.8%
1987	11	94.7	18.83	19.9%
1990	20	118.7	32.29	27.2%
1991	11	108.7	17.22	15.8%
1993	5	108.8	30.64	28.2%
1994	11	74.5	17.59	23.6%
1997	14	122.2	26.68	21.8%
1998	19	94.9	23.40	24.6%
2001	208	109.9	22.42	20.4%

Table 9. Average total length, standard deviation, and range of Lower Klamath River green sturgeon harvested in tribal fisheries from 1980 through 1992 (Table 36, p 58, USFWS 1994). Data for 1980-1985 are from fish taken in gill nets, beach seine, and by hook and line. Data from 1986 to 1992 are for gill-netted sturgeon only.

Year	Mean Total Length (cm)	Standard Deviation	Sample Size	Range (cm)
1980	173.0	15.25	90	148 - 211
1981	176.3	17.62	157	138 - 232
1982	170.7	18.78	82	130 - 216
1983	170.9	13.64	45	145 - 208
1984	175.0	16.29	65	140 - 214
1985	174.8	17.44	34	130 - 208
1986	169.2	20.99	21	134 - 210
1987	176.9	23.71	21	143 - 260
1988	178.8	23.20	16	139 - 218
1989	169.5	20.05	20	136 - 196
1990	178.4	20.71	51	129 - 217
1991	179.9	19.76	63	130 - 222
1992	178.3	23.94	35	134 - 238

Table 10. Sturgeon catch during tagging, ratios of green to white sturgeon in the catch, and abundance estimates, 1954-2001.

									Legal-sized white sturgeon abundance	Legal-sized green sturgeon abundance
	Legal (>=102 cm)				Sublegal (<102 cm)					
Year	White	Green	W/G	G/W	White	Green	W/G	G/W		
1954	961	17	56.5	0.018	33	8	4.1	0.242	11,200	198
1967	1,612	26	62.0	0.016					114,700	1,850
1968	1,080	28	38.6	0.026					40,000	1,037
1974	713	7	101.9	0.010	62	103	0.6	1.661	20,700	203
1979	1,368	26	52.6	0.019	62	9	6.9	0.145	100,300	1,906
1984	2,551	24	106.3	0.009	148	7	21.1	0.047	117,600	1,106
1985	2,419	19	127.3	0.008	68	47	1.4	0.691	107,800	847
1987	982	6	163.7	0.006	42	5	8.4	0.119	97,800	598
1990	596	12	49.7	0.020	353	8	44.1	0.023	75,600	1,522
1991	403	5	80.6	0.012	529	6	88.2	0.011	72,700	902
1993	207	2	103.5	0.010	271	3	90.3	0.011	46,700	451
1994	274	0		0.000	552	11	50.2	0.020		
1997	1,015	8	126.9	0.008	354	6	59.0	0.017	141,900	1,118
1998	1,263	3	421.0	0.002	275	16	17.2	0.058	144,400	343
2001[a]	771	23	33.5	0.030	173	62	2.8	0.358	120,000	3,580
Total	16,215	206	78.7	0.013	2,922	291	10.0	0.100		

[a] Excluding August catches

Table 11. Estimated harvest of green sturgeon in the Klamath River. Data provided by J. Devore, Washington Department of Fish and Wildlife and S. King, Oregon Department of Fish and Wildlife. (from Appendix 2 of the listing petition)

Year	Yurok[2]	Hoopa[3]	Karuk[4]	Poaching[5]	Total
1980	700+	-	unknown	400+	1100+
1981	880+	-	unknown	70+	950+
1982	397+	-	unknown	50+	447+
1983	406+	-	unknown	unknown	406+
1984	394+	-	unknown	unknown	394+
1985	351+	10	unknown	unknown	361+
1986	421+	30	unknown	unknown	451+
1987	171+	20	unknown	unknown	191+
1988	212+	20	unknown	unknown	232+
1989	268+	30	unknown	unknown	298+
1980s average	420+	22	unknown	unknown	483+
1990	242+	20	unknown	unknown	262+
1991	312+	13	unknown	unknown	325+
1992	212+	3	unknown	unknown	215+
1993	417+	10	unknown	unknown	427+
1994	293+	14	unknown	unknown	307+
1995	131+	2	unknown	unknown	133+
1996	119+	17	unknown	unknown	136+
1997	306+	7	unknown	unknown	313+
1998	335+	10	unknown	unknown	345+
1999	184+	27	unknown	unknown	211+
1900s average	255+	12	unknown	unknown	267+

[a] Available harvests estimates are biased low by variable and inconsistent sampling efforts based on voluntered data.
[b] Some Yurok harvest occurs prior to annual monitoring activities of the USFWS.
[c] USFWS data onlv available from 1985. Available harvest estimates are biased low by variable and inconsistent sampling effort based on volunteered data.
[d] Karuk harvest is not monitored by the USFWS.
[e] Illegal snag harvest occurred at Coon Creek Falls after 1977, where a debris slide created a migration obstacle.

Table 12. Annual estimates of harvest rate and catch for green sturgeon tagged in the Sacramento-San Joaquin Estuary.

Year	Tagged	1st -year returns	Harvest rate	Abundance	Catch
1948	36	1	0.028		
1949	6	0	0		
1954	27	0	0		
1967	25	0	0		
1968	28	0	0		
1974	7	0	0		
1979	26	2	0.077	1,906	147
1984	24	1	0.042	1,106	46
1985	19	1	0.053	847	45
1987	6	0	0		
1990	12	0	0		
1991	5	0	0		
1993	2	0	0		
1994	0	0	0		
1997	8	0	0		
1998	0	0	0		
2001	45	Incomplete			
Overall			0.022[a]		

[a] Excluding 2001, for which 1st year returns are not complete.

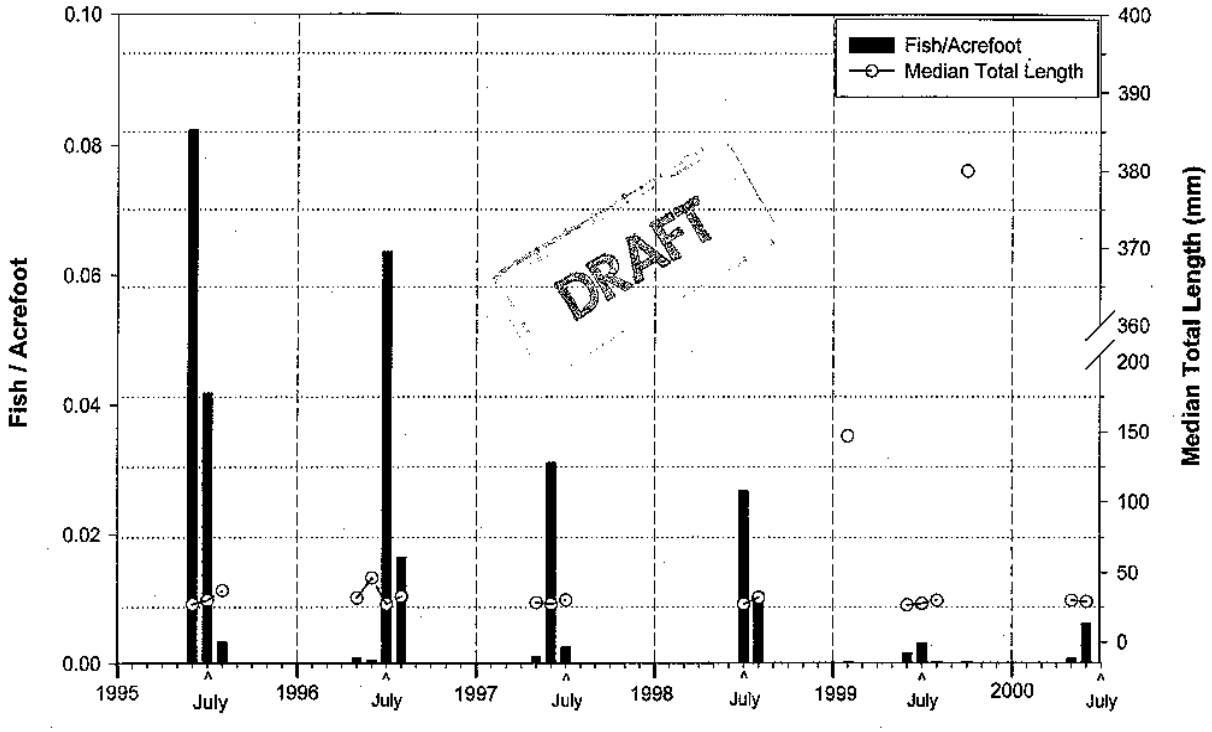

Figure 1. Monthly catch per acre-foot and median total length of sturgeon sampled in rotary-screw traps at Red Bluff Diversion Dam, 1995-2000 (Figure 1 in Gaines and Martin 2001).

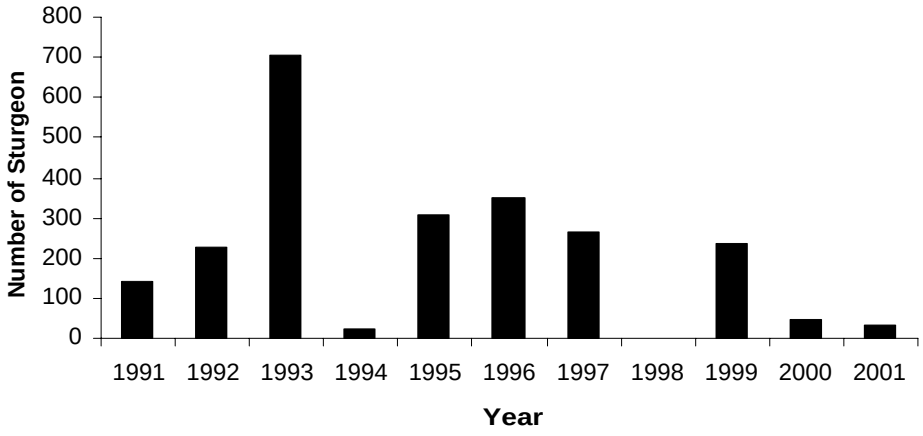

Figure 2. Annual catch of sturgeon <100 mm FL at the Glenn-Colusa Irrigation District bypass rotary-screw trap from 1991 to 2001. The trap was not fished in 1998.

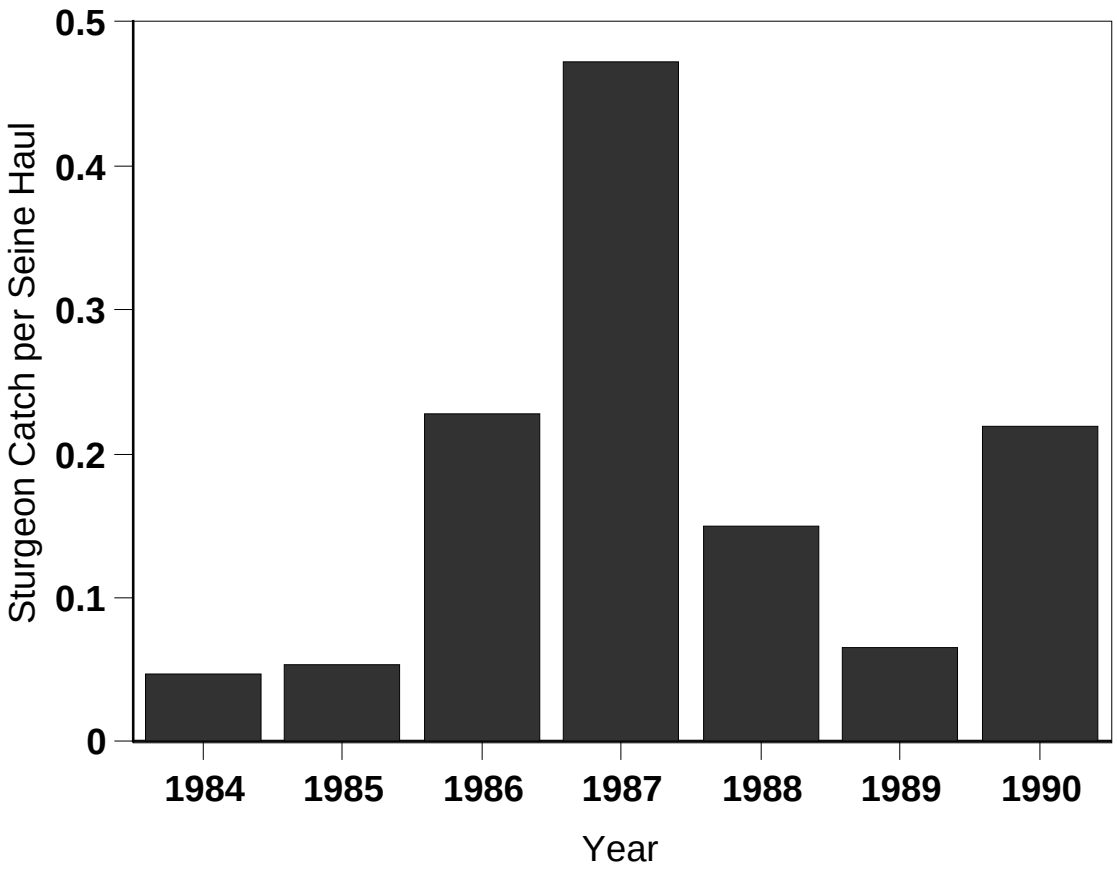

Figure 3. Annual catch per seine haul of green sturgeon in the Klamath River estuary, 1984-1990.

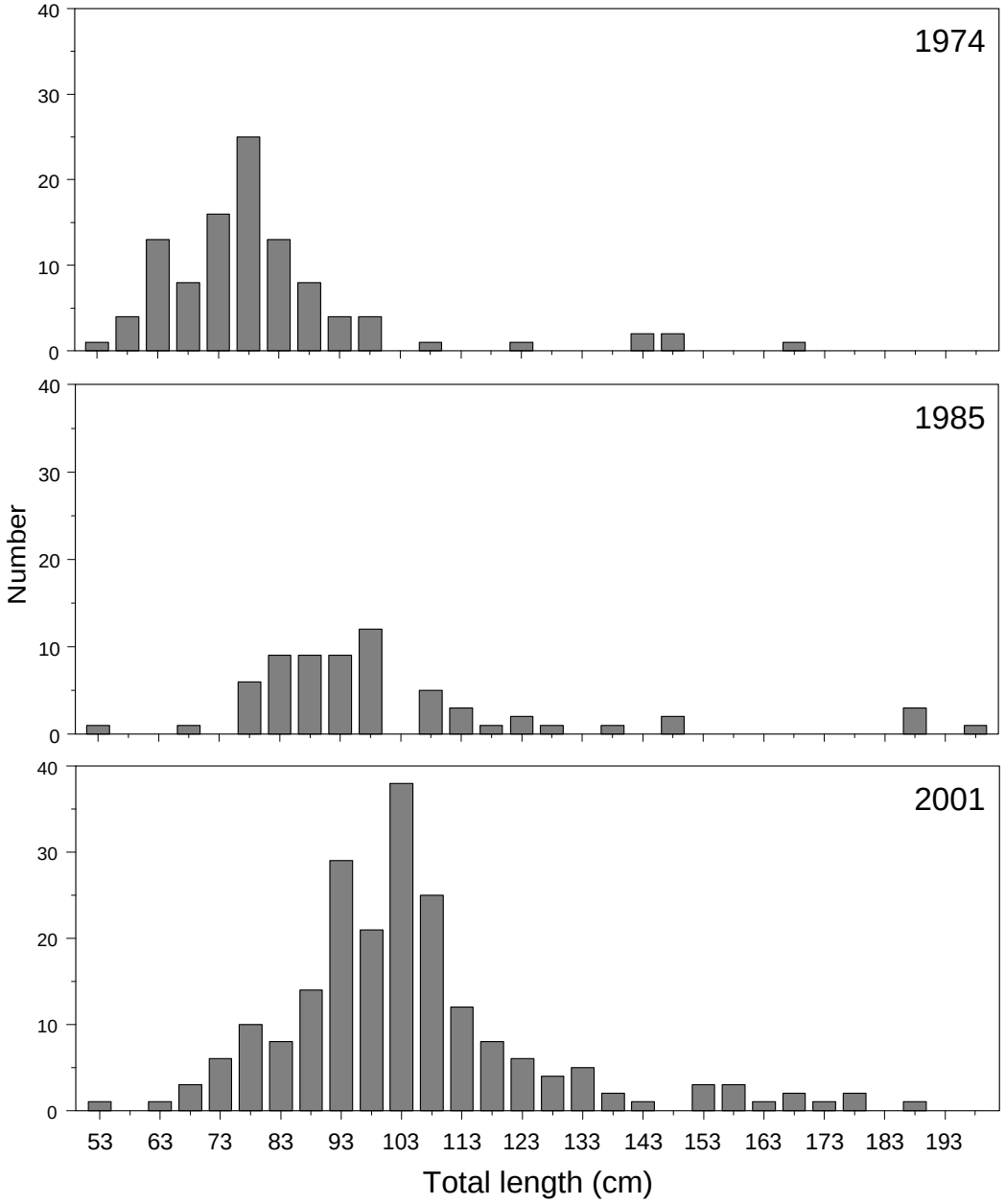

Figure 4.
Total length frequencies of green sturgeon captured during tagging in the Sacramento-San Joaquin Estuary in 1974, 1985, and 2001.

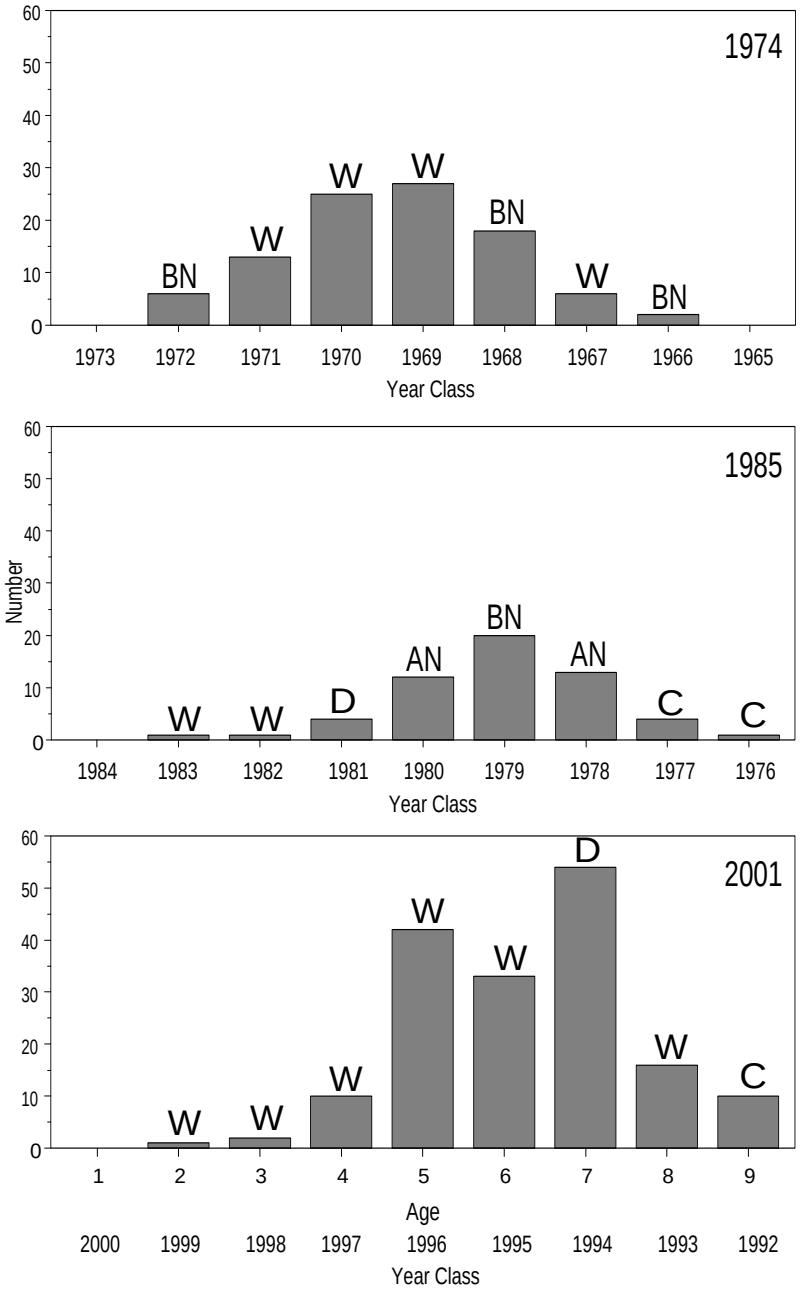

Figure 5. Estimated age frequency of green sturgeon ≤ age 9 captured during tagging in the Sacramento-San Joaquin Estuary in 1974, 1985, and 2001. Letters above bars indicate year types, where C = critically dry, D = dry, BN = below normal, AN = above normal, and W = wet.

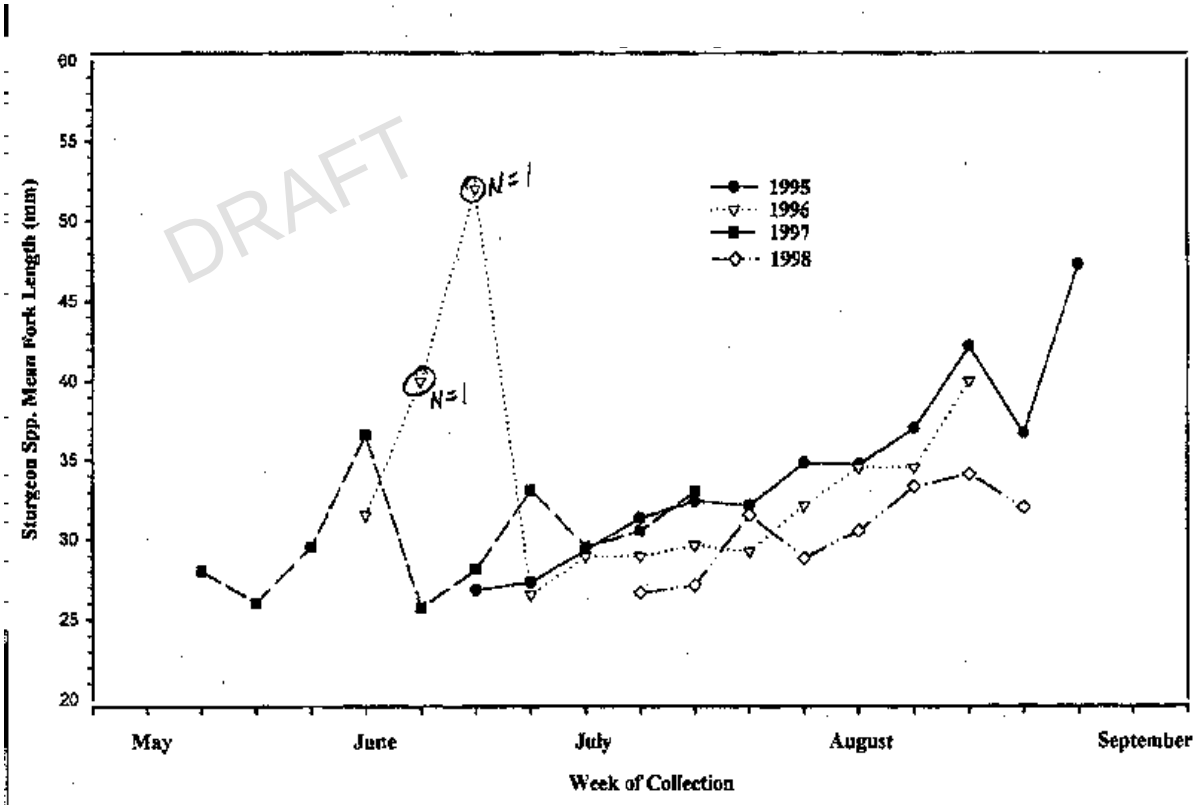

Figure 6. Mean fork length of sturgeon captured weekly by rotary-screw traps at the Red Bluff Diversion Dam from 1995 to 1998. Figure 1 in February 9, 1999 memorandum from P. Gaines, USFWS to P. Ward, CDFG. (For original data, contact Phillip Gaines, USFWS, Red Bluff, California.)

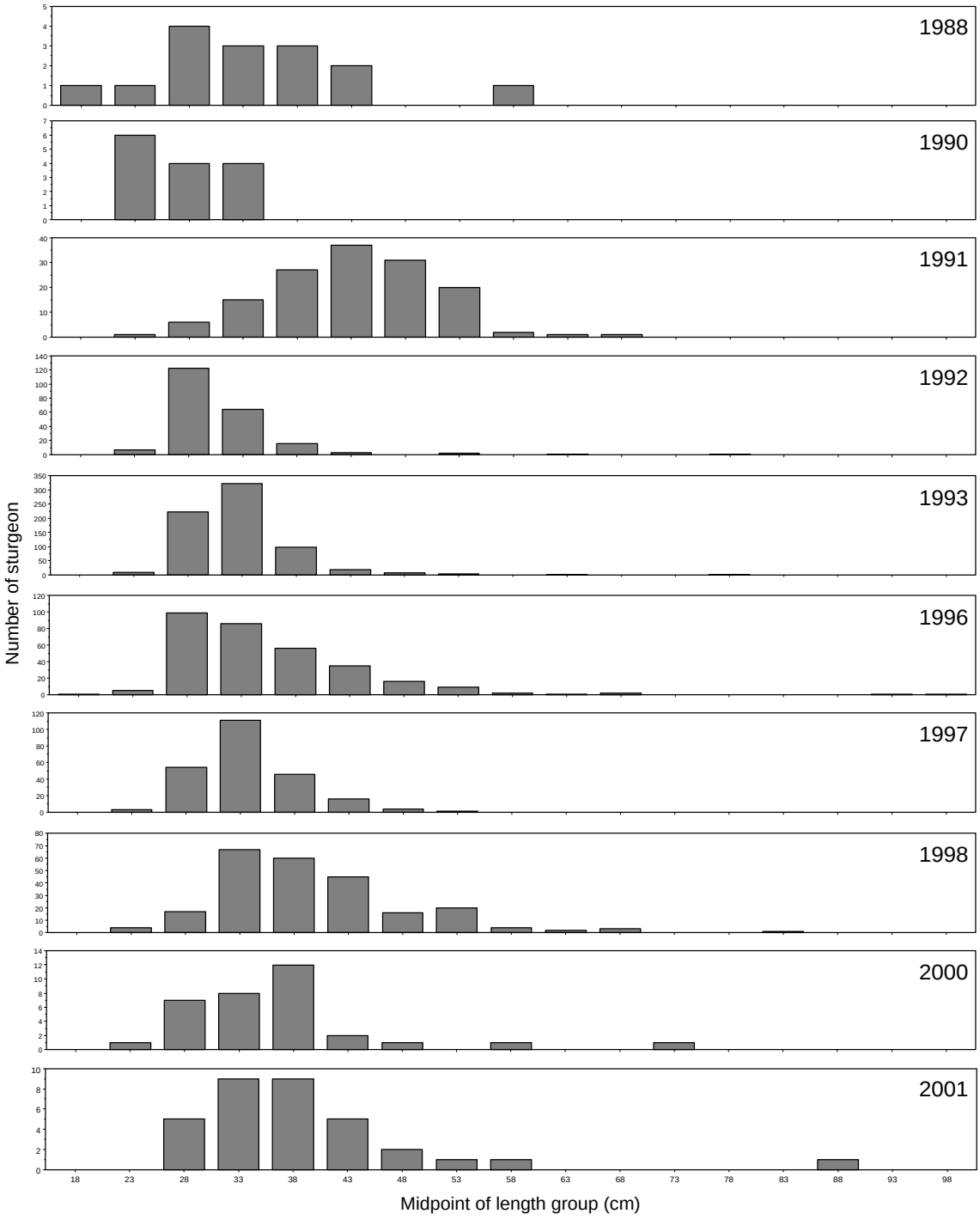
1988
1990
1991
1992
1993
1996
1997
1998
2000
2001
Number of sturgeon
18
23
28
33
38
43
48
53
58
63
68
73
78
83
88
93
98
Midpoint of length group (cm)

Figure 7. Length frequency distribution of sturgeon <100 mm caught by the Glenn-Colusa Irrigation District rotary-screw trap from 1988 to 2001. Data from 3 years are not included: only one 47-mm fish was caught in 1989 and individual lengths are not available for 1994 and 1995. Length measurements are total length in 1988-1993 and fork length in 1996-2001. Note that scale on the ordinate varies between years as catches differed annually.

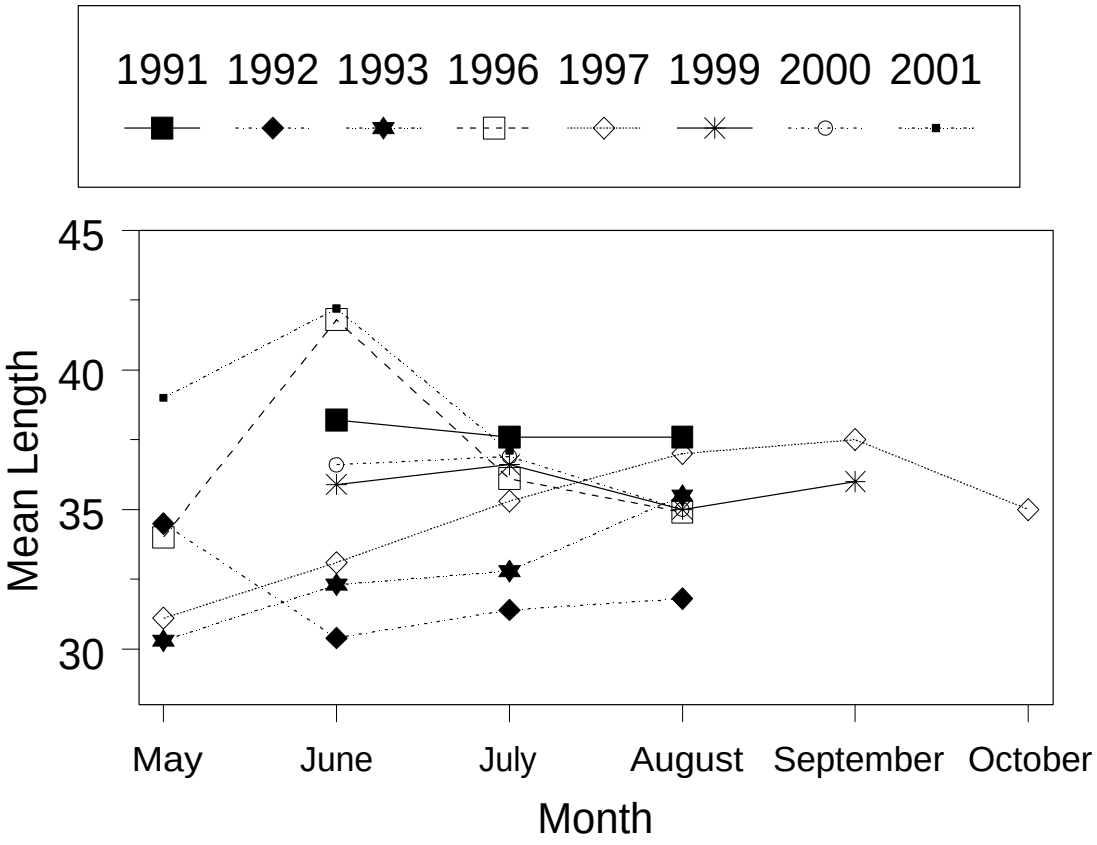
1991 1992 1993 1996 1997 1999 2000 2001
45
40
35
30
Mean Length
May
June
July
August
September
October
Month

Figure 8. Monthly mean lengths of sturgeon <100 mm caught by the Glenn-Colusa Irrigation District rotary-screw trap from 1991 to 2001. Years with <3 months data and months with only 1 fish measured are excluded. Length measurements are total length in 1988-1993 and fork length in 1996-2001. Data are in Appendix C.

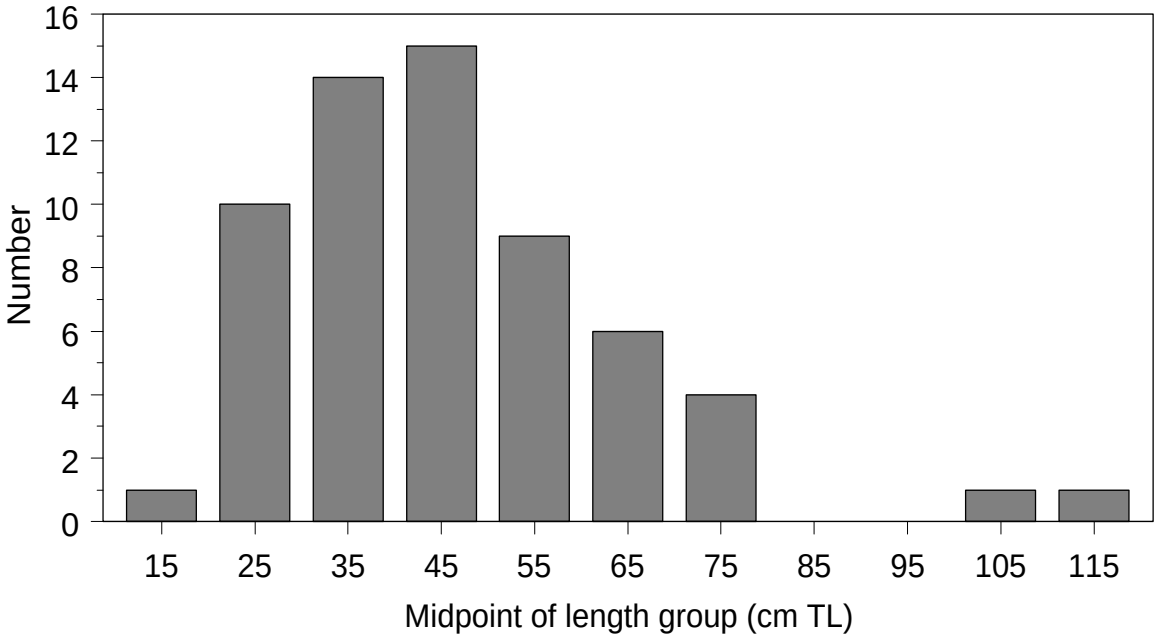

Figure 9. Length frequency of green sturgeon caught in otter and midwater trawls by the San Francisco Bay Outflow Study from 1980 to 2001.

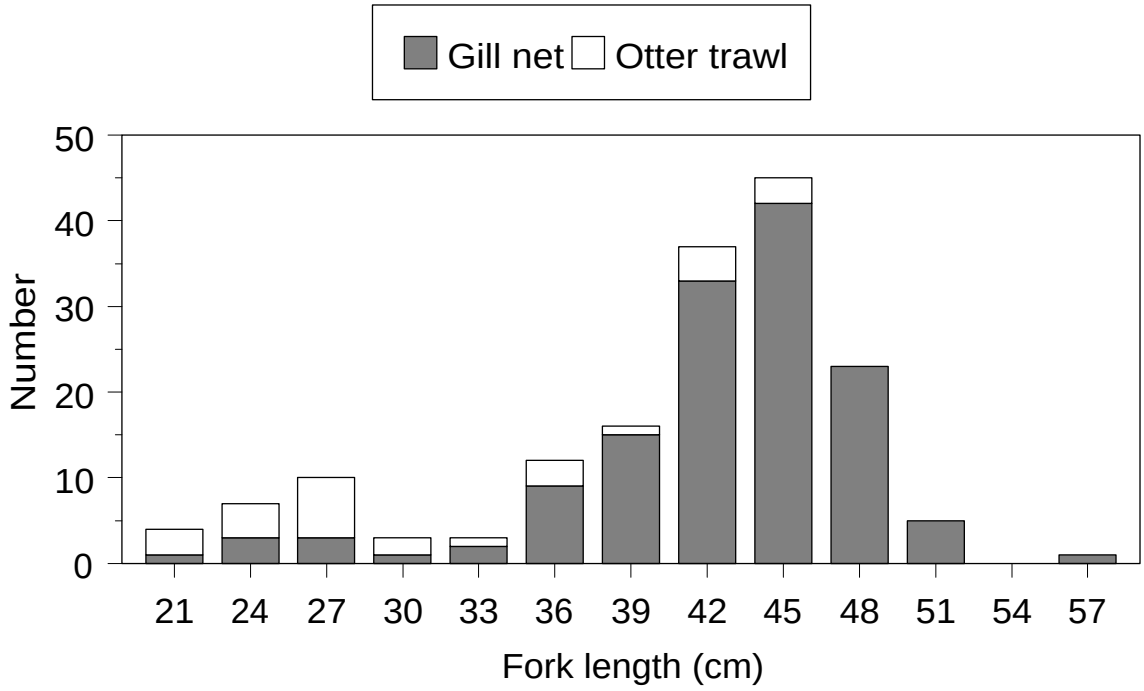

Figure 10. Length frequency distribution of green sturgeon caught in the Sacramento-San Joaquin Delta with gill nets and otter trawl from September 1963 to August 1964 (After Radtke 1966, Figure 7).

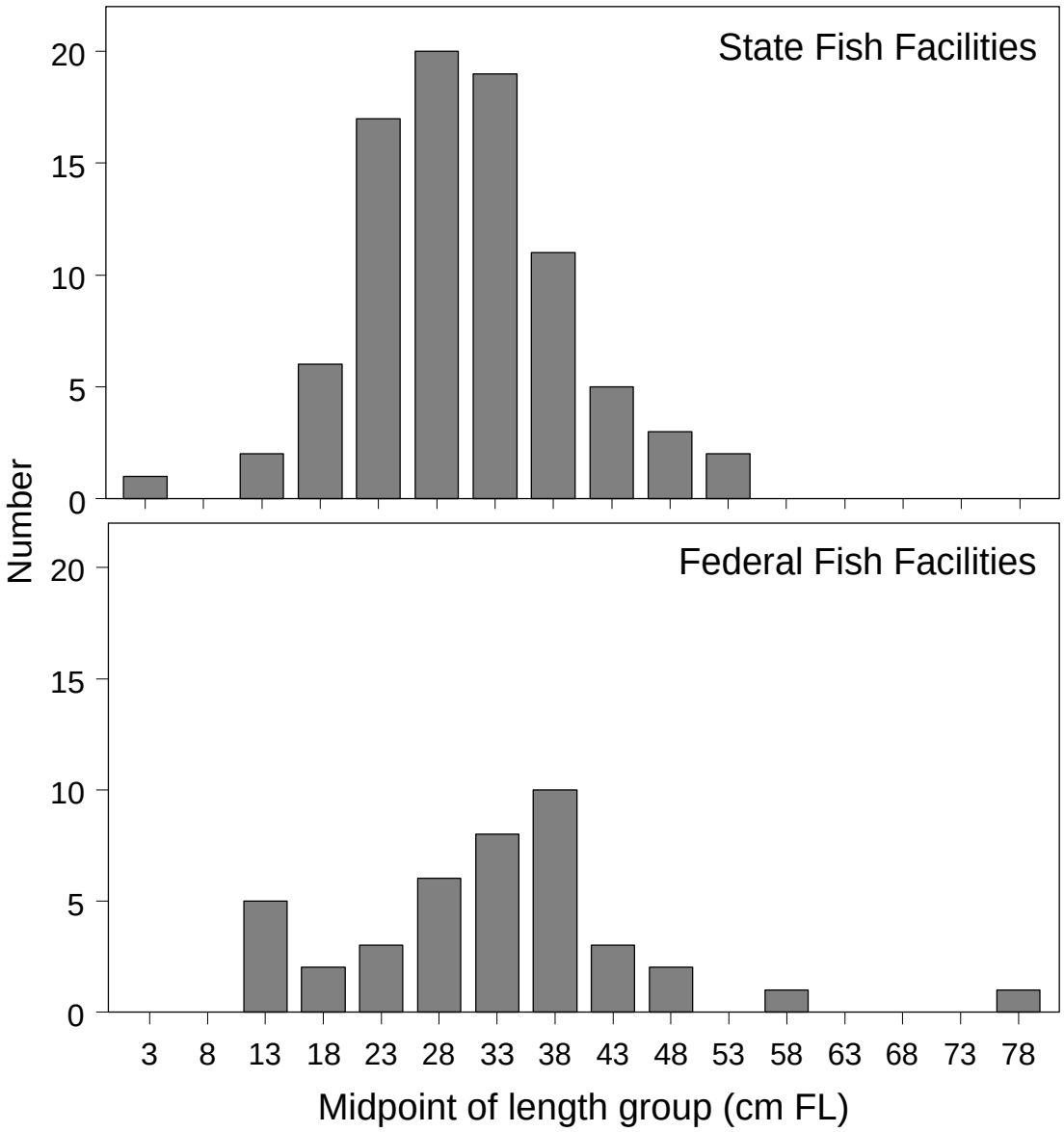
State Fish Facilities
Federal Fish Facilities
Number
0
5
10
15
20
3
8
13
18
23
28
33
38
43
48
53
58
63
68
73
78
Midpoint of length group (cm FL)

Figure 11. Length frequency distribution of green sturgeon collected at the state and federal fish facilities in the South Sacramento-San Joaquin Delta from 1968 to 2001.

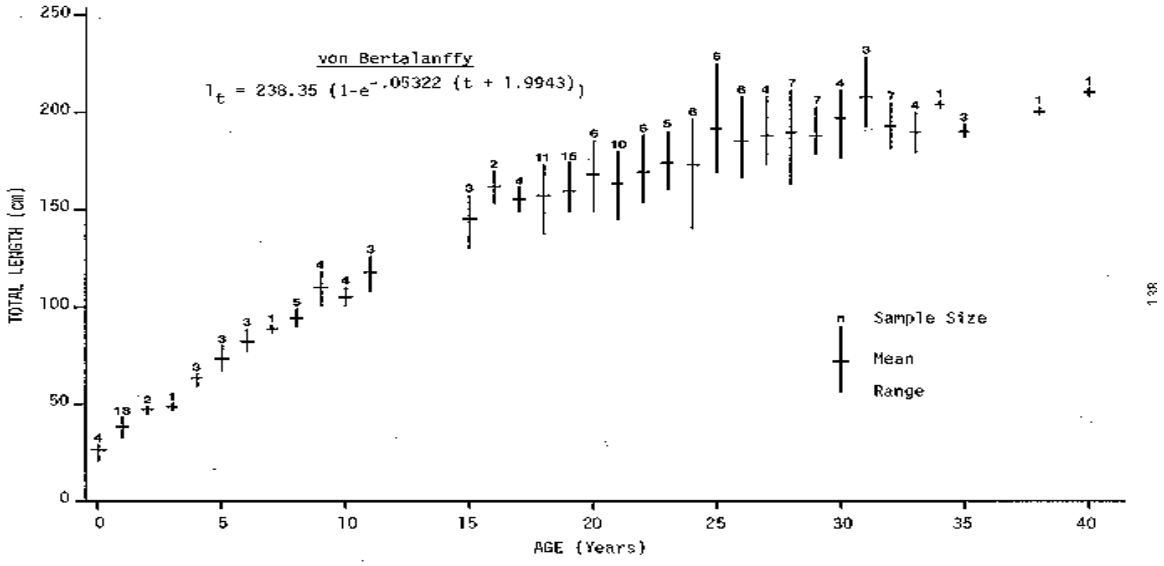

Figure 12. Length-age relation for Klamath River green sturgeon collected during 1979-1982, including a von Bertalanffy growth equation for ages 1-30 (Figure 51, page 138, USFWS 1993).

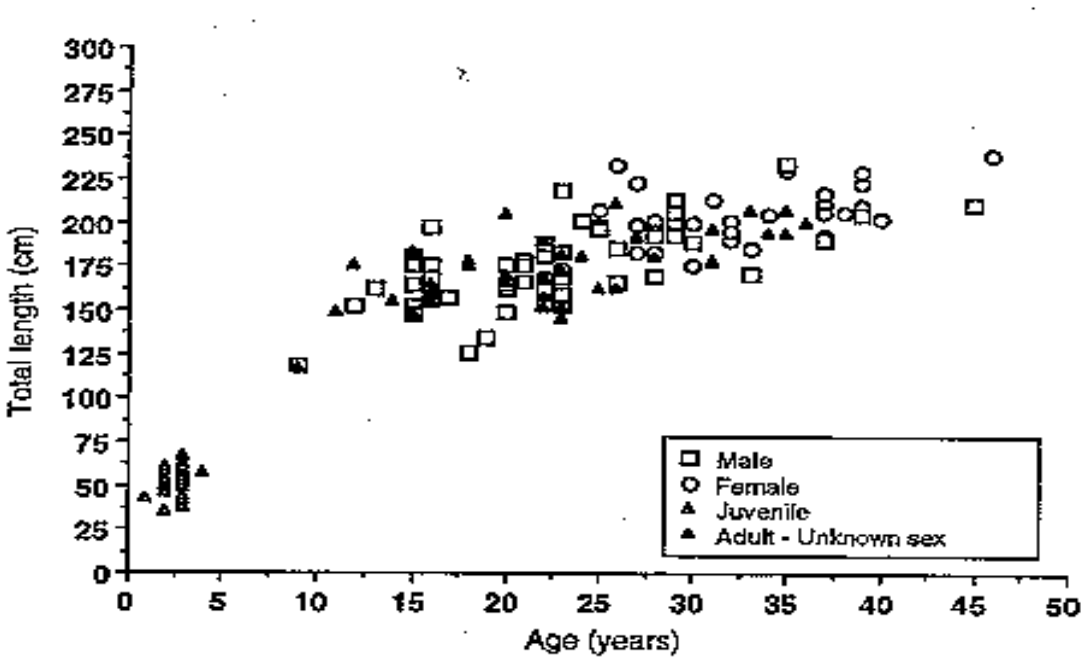

Figure 13. Length-age relation for green sturgeon from the Klamath River, 1990-1993 (Figure 4, page 10, Nakamoto and Kisanuki 1995).

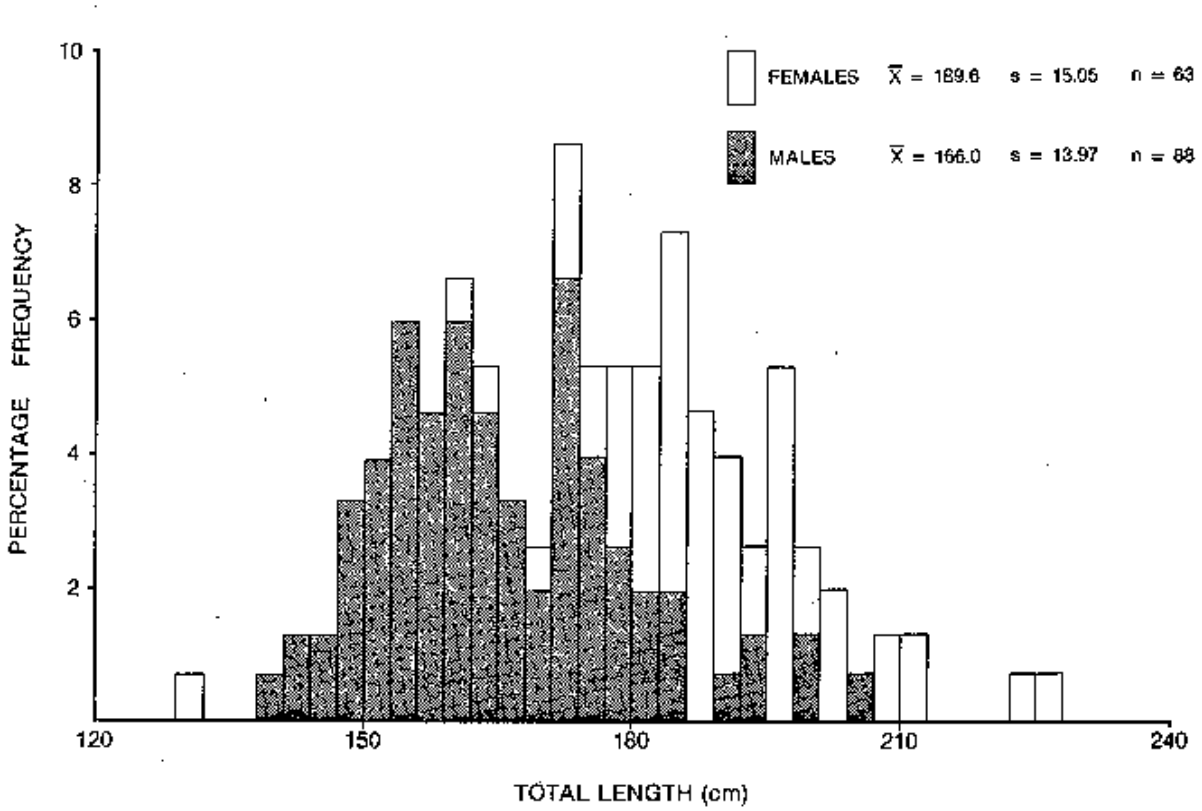

Figure 14. Combined length frequency distribution of Klamath River adult male and female green sturgeon captured during 1980-1983 by beach seine, gill net and hook and line (Figure 53, page 128, USFWS 1984).

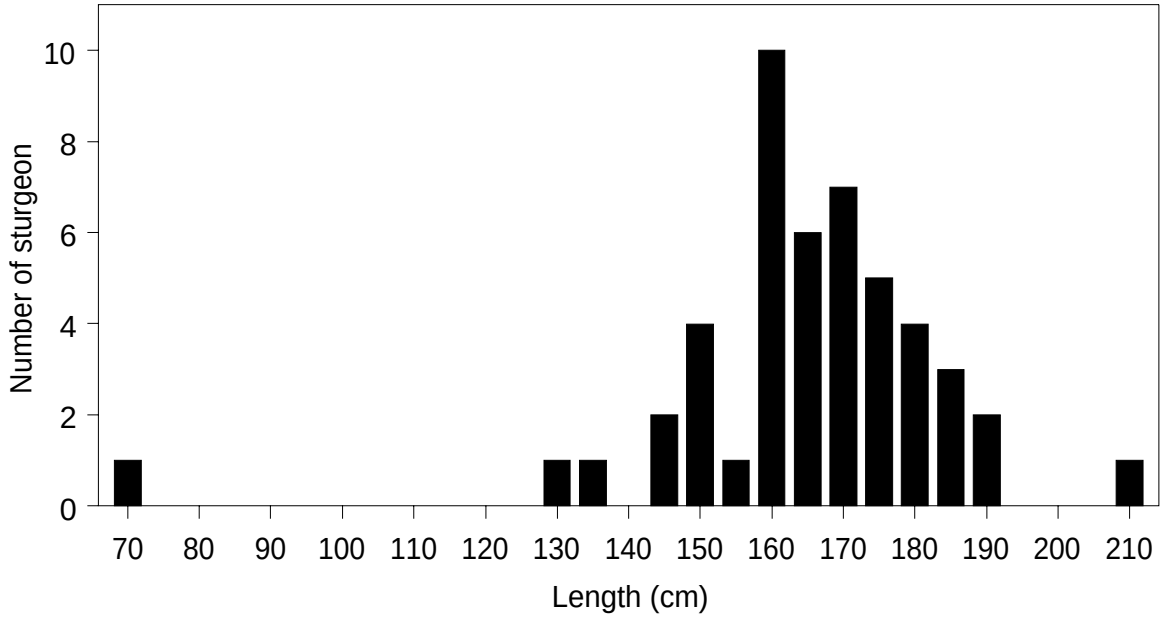

Figure 15. Length frequency of green sturgeon seined in the Klamath River estuary, May 17 to August 1, 1977. Method of measurement (fork or total length) was not recorded.

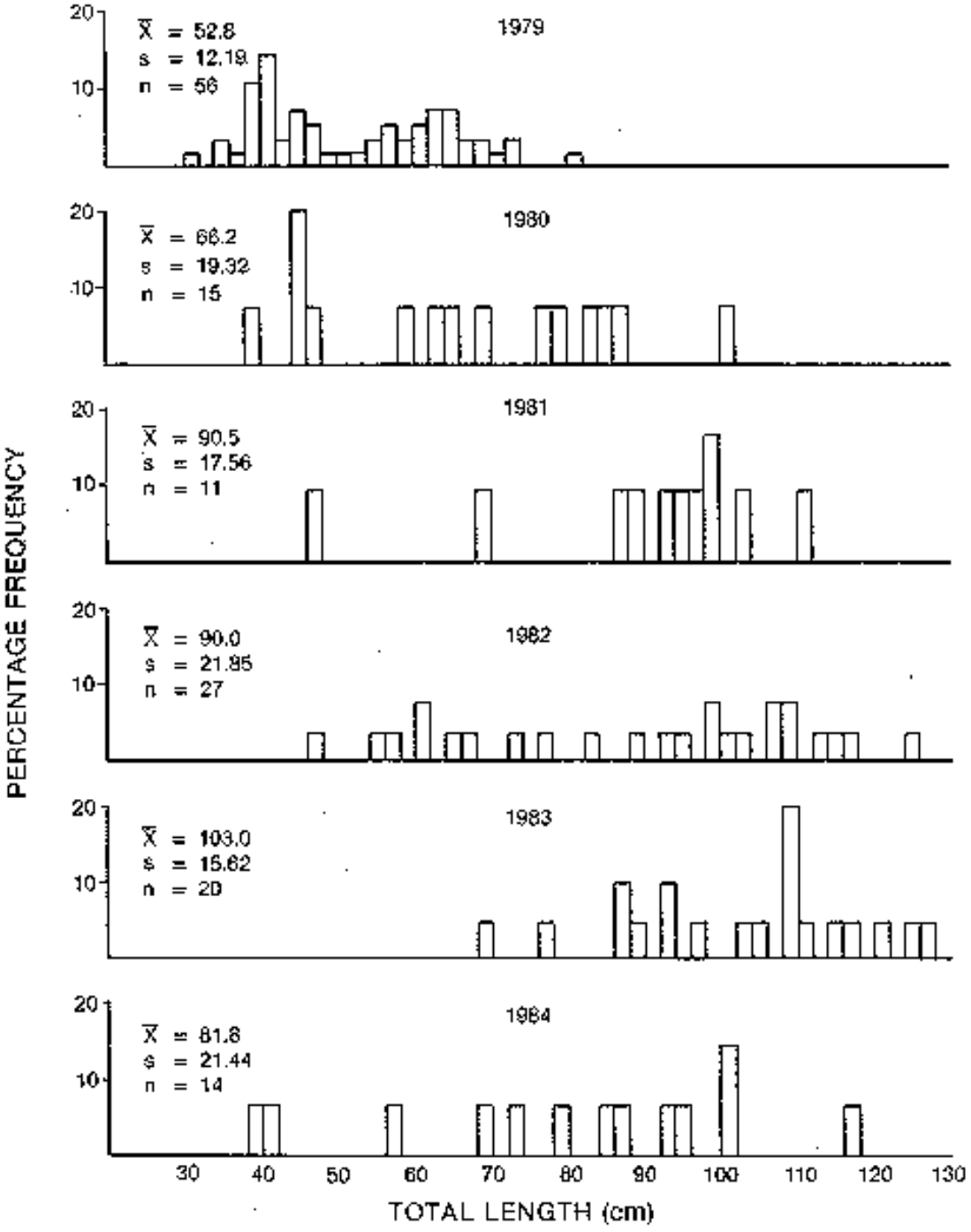
1979
X̄ = 52.8
s = 12.19
n = 56
1980
X̄ = 66.2
s = 19.32
n = 15
1981
X̄ = 90.5
s = 17.56
n = 11
1982
X̄ = 90.0
s = 21.85
n = 27
1983
X̄ = 103.0
s = 15.62
n = 20
1984
X̄ = 81.8
s = 21.44
n = 14
PERCENTAGE FREQUENCY
TOTAL LENGTH (cm)

Figure 16. Length frequency distributions of green sturgeon captured by beach seine and gill net in the Klamath River estuary, 1979-1984 (Figure 47, page 136, USFWS 1985).

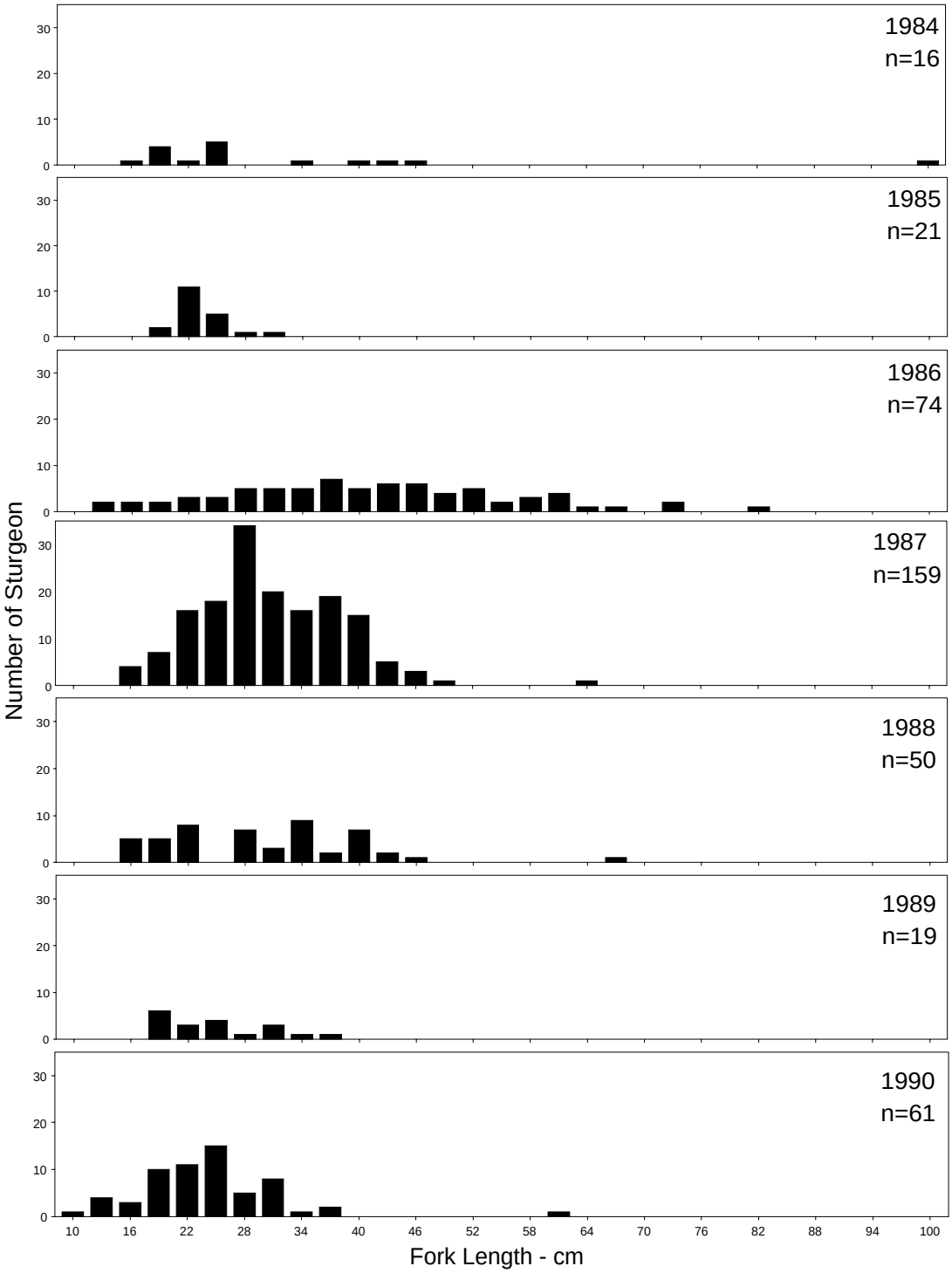

Figure 17. Length frequency of juvenile green sturgeon captured in California Department of Fish and Game beach seining in the Klamath River estuary, 1984-1990.

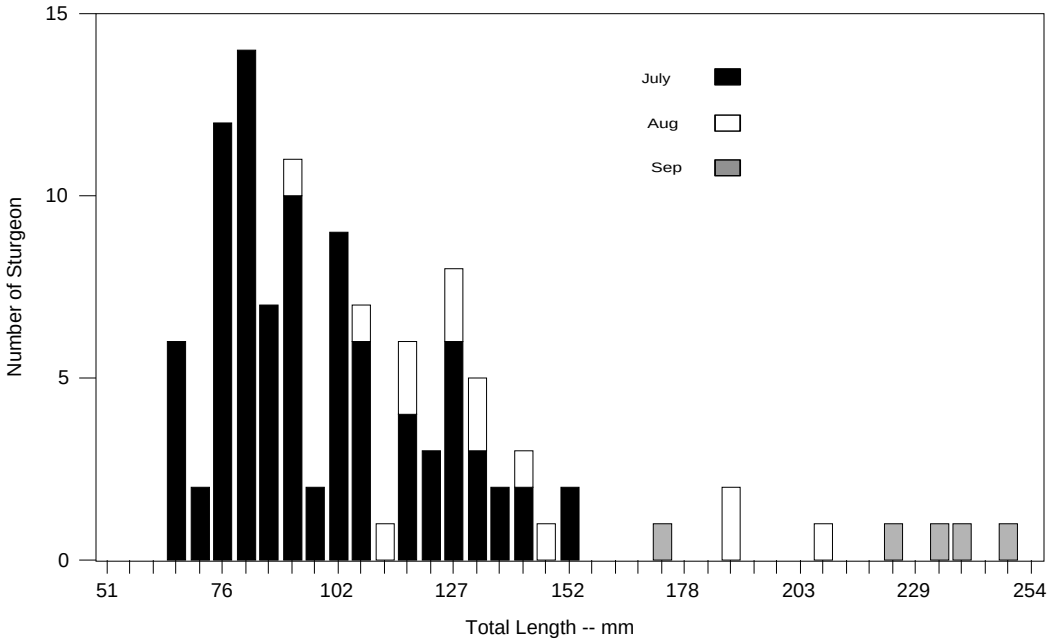

Figure 18. Length by month of YOY green sturgeon captured by fyke net in the Trinity River near Willow Creek in 1968 (Healey 1973).

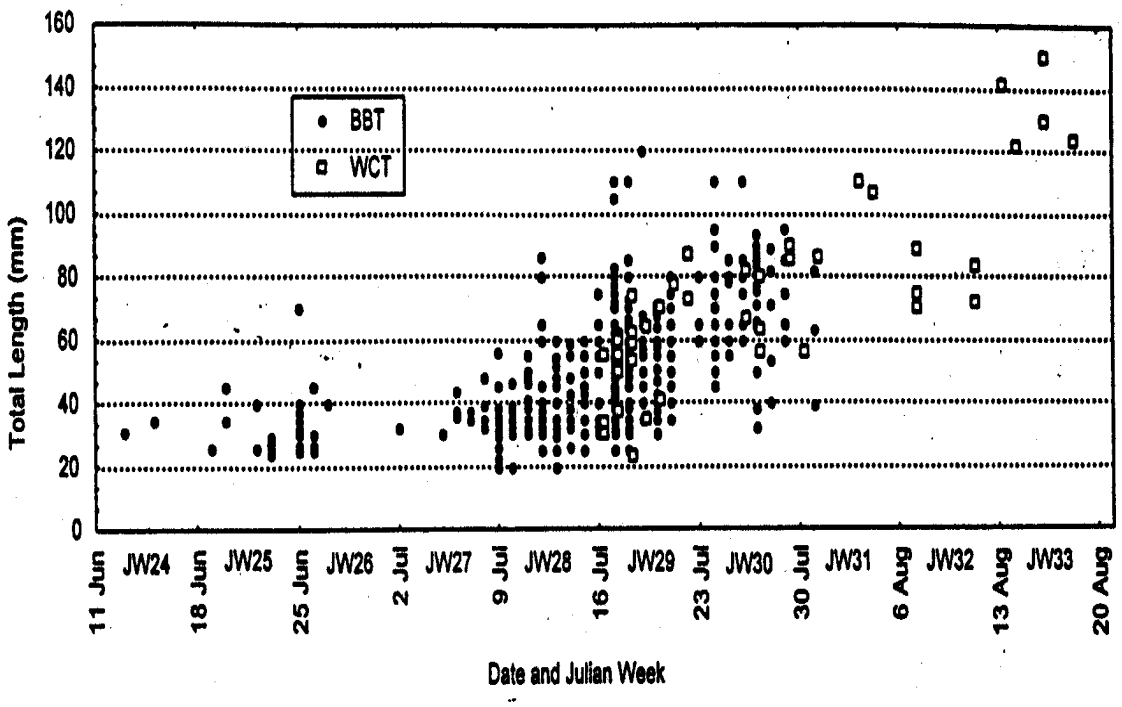

Figure 19. Daily lengths of green sturgeon captured in rotary-screw traps at Big Bar on the Klamath River (BBT) and Willow Creek on the Trinity River (WCT) in 1996 (Figure 32, page 63, USFWS 1999).

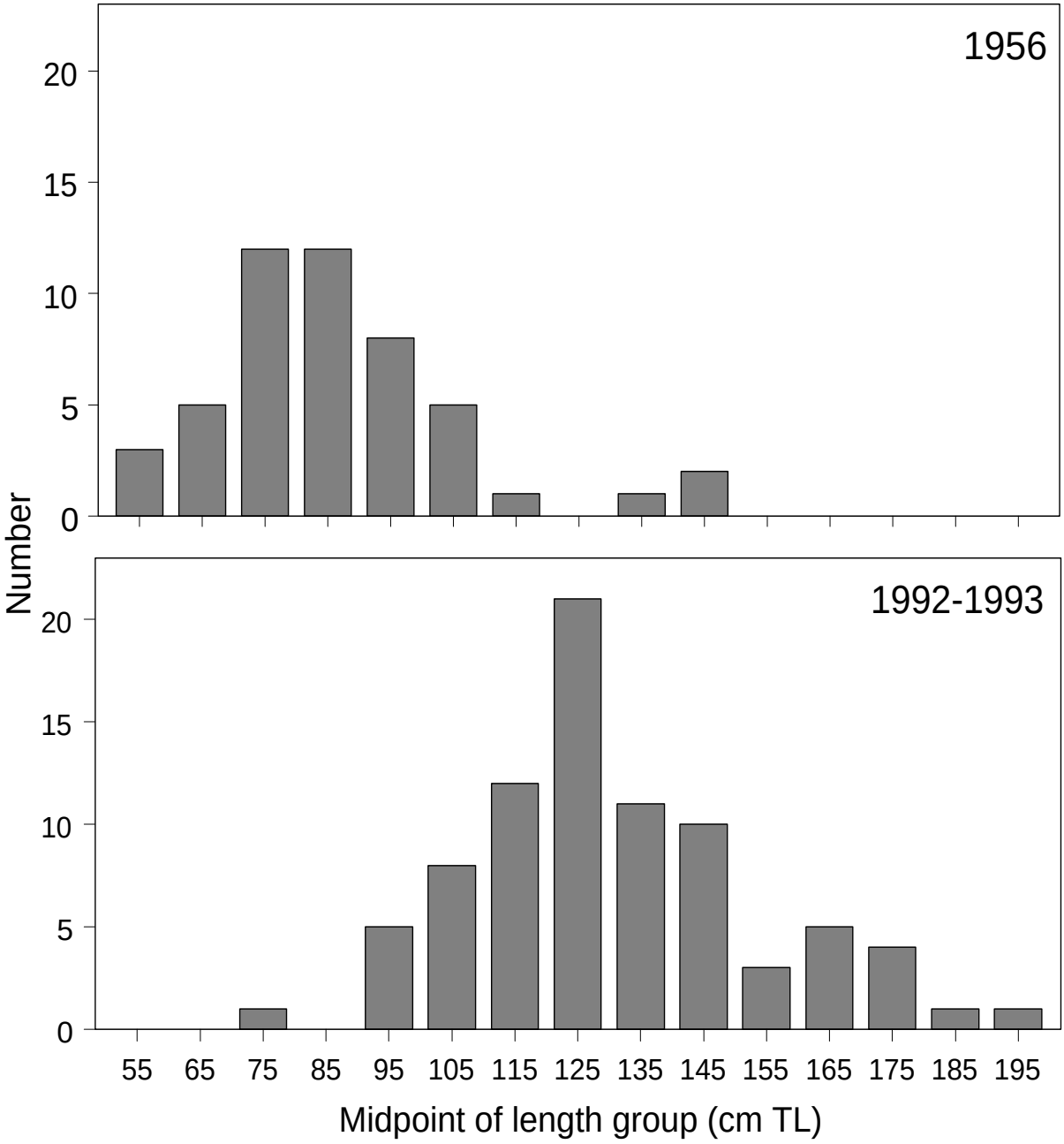

Figure 20. Length frequency distribution of green sturgeon tagged in Arcata Bay in 1956 and 1992-1993.

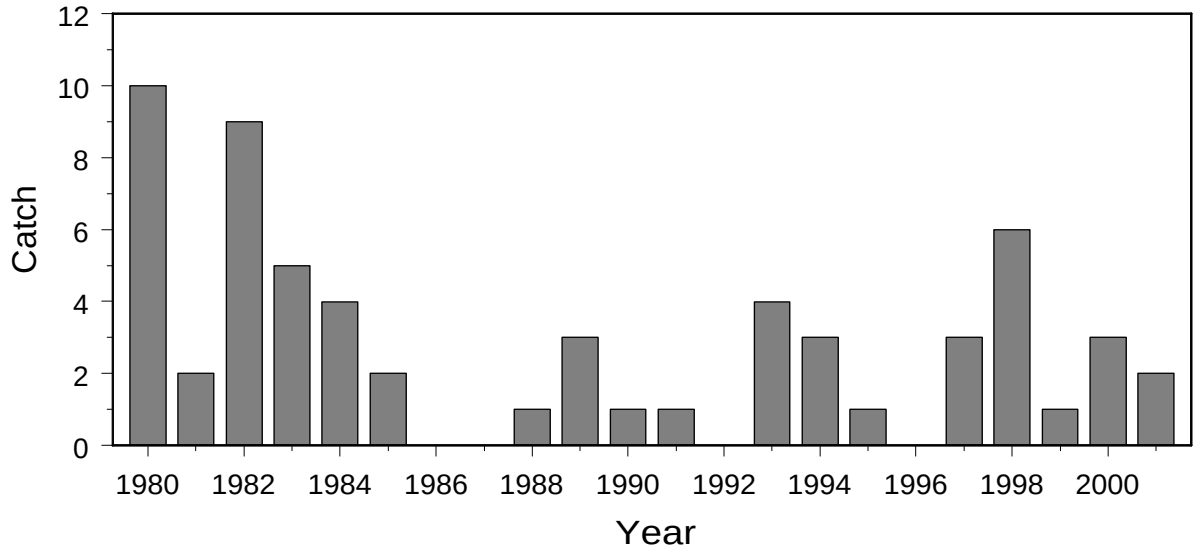

Figure 21. San Francisco Bay Study catch of green sturgeon in otter and midwater trawls.

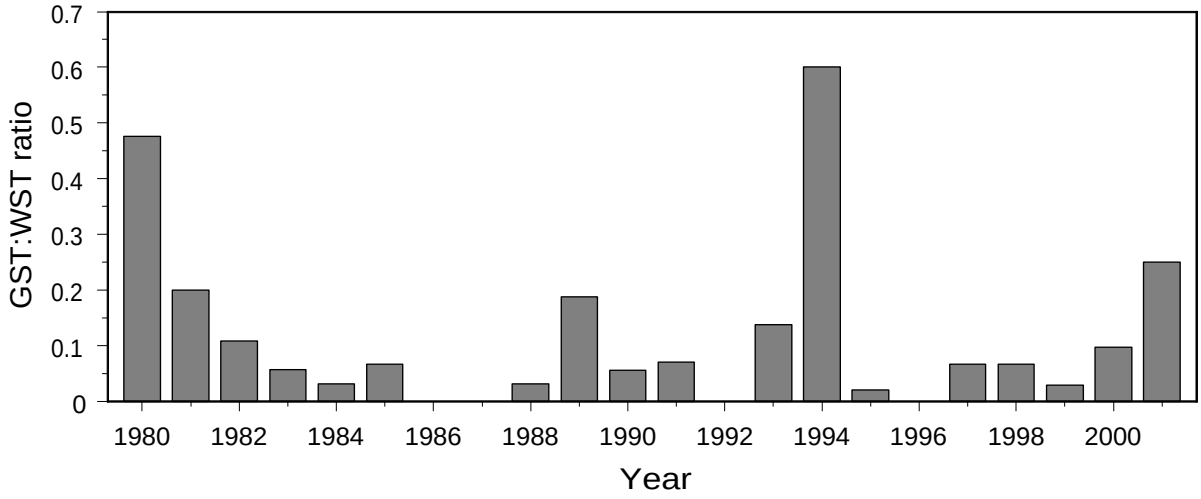

Figure 22. Green sturgeon:white sturgeon ratio in otter and midwater trawl catches by the San Francisco Bay Study.

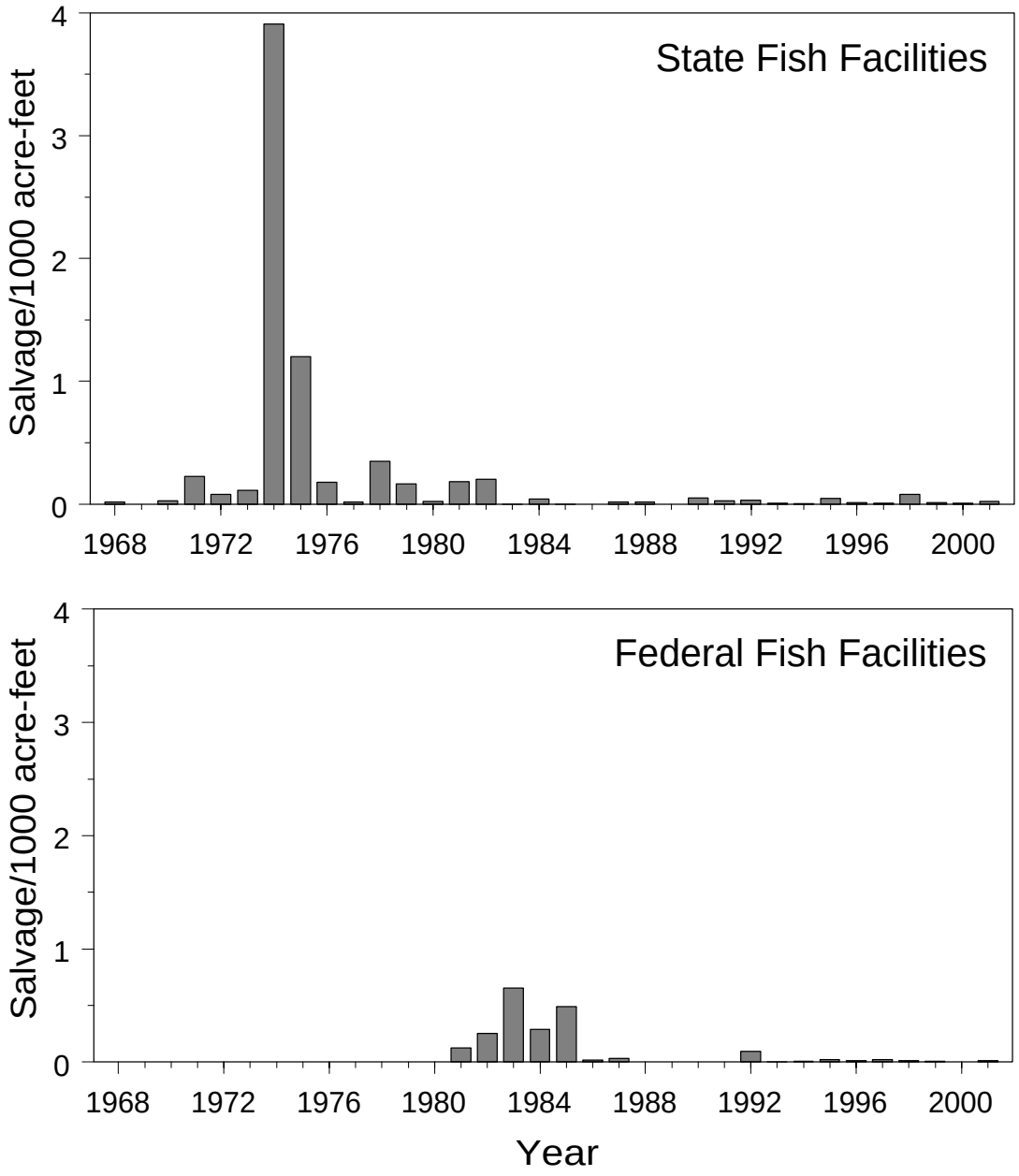
State Fish Facilities
Federal Fish Facilities
Salvage/1000 acre-feet
Year
0
1
2
3
4
1968
1972
1976
1980
1984
1988
1992
1996
2000

Figure 23. Estimated annual salvage of green sturgeon per 1000 acre-feet of water exported at the state and federal fish facilities in the south Sacramento-San Joaquin Delta.